Taggants in Explosives

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Foreword

This assessment was made in response to a request from the Senate Committee on Governmental Affairs that OTA examine the issues surrounding a proposal to require that commercial explosives and gunpowders be manufactured with "taggants" as an aid to law enforcement. Two types of taggants are contemplated:

- "identification taggants" would be designed to survive an explosion and would carry a code which would enable those who recovered such taggants from the debris of a criminal bombing to assemble a list of the last legal purchasers of the batch of explosives used to make the bomb.
- detection taggants" would be designed to emit a vapor which would escape from a suitcase, package, etc., so that a taggant-sensing machine at an airport or public building could detect the presence of concealed explosives.

The proposal to require taggants is generally viewed as helpful by the law enforcement community, and opposed by the manufacturers of explosives (and some others) on the grounds that taggants would be ineffective, unsafe, and too costly.

The report addresses four major questions. First, it reviews the program to develop such taggants, and addresses the question of whether taggants would in fact work. Second, it assesses the question of whether adding such taggants to explosives and gunpowders might create a safety hazard. Third, the cost of a taggant program (on the assumption taggants work and are safe) is calculated, and the major parameters which would affect its costs are identified. Finally, the study assesses the likely value of such a program (assuming that taggants work, are safe, and are available at a reasonable cost) to law enforcement.

The project was directed by Dr. Peter Sharfman, Program Manager for International Security and Commerce within OTA's Energy, Materials, and International Security Division, headed by Assistant Director Lionel S. Johns. The principal investigator was David Garfinkle of Science Applications, Inc.

OTA is grateful for the assistance of its Taggants in Explosives Advisory Panel as well as for the assistance provided by the Bureau of Alcohol, Tobacco, and Firearms of the U.S. Department of the Treasury, the Institute of Makers of Explosives, the Sporting Arms and Ammunition Manufacturers Institute, the 3M Company, and the Federal Aviation Administration.

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NOTE: The advisory panel provided advice and critique throughout the assessment, but does not necessarily approve, disapprove, or endorse the report for which OTA assumes full responsibility.

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SUMMARY

Chapter I.-SUMMARY

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INTRODUCTION

At the request of the Senate Committee on Governmental Affairs, the Office of Technology Assessment has undertaken an analysis of the proposal to mandate the use of taggants in explosive materials manufactured for commercial use. A "taggant" is a material that might be added to explosives and gunpowders* at the time of manufacture as an eventual aid to law enforcement. The study assesses the existing taggant technology in order to assist Congress in its decision whether to adopt legislation which would require taggants in explosives and gunpowders.

Two different kinds of taggants are being developed for possible incorporation in chemical explosives, and it has been proposed that both be required. Identification taggants are designed to survive the detonation of an explosive and to be retrieved from the debris. They would contain a code identifying the batch of explosives or gunpowder used in a particular bombing. The intent of those advocating the development of such taggants is that law enforcement officers investigating a criminal bombing would retrieve identification taggants and decode them, could then begin their investigation knowing what kind of explosive material had been used, and would be able to obtain a list of the last legal purchasers of these explosives and gunpowders. At the present time the leading contender for an identification taggant is a color-coded microscopic plastic chip which has been developed by the 3M Co.

Detection taggants are designed to be sensed by a suitable detection machine even when contained in a package. The intent of those developing detection taggants is that detection machines at airports, public building entrances, and other appropriate sites would signal any effort to introduce explosive materials into the area. In facilities not normally protected by such devices, portable detection sensors could be used to search the facility in response to a threat. The leading contender for a detection taggant is a microcapsule which would emit small quantities of a vapor whose molecules are so distinctive that a suitable sensing instrument (which is under parallel development) could detect a parts-per-trillion concentration.

The Bureau of Alcohol, Tobacco and Firearms (BATF) of the Department of the Treasury, which is the executive agency that has jurisdiction over most crimes involving high explosives, has sponsored a program to develop taggants. Most of the effort has been carried out or supervised by the Aerospace Corp. under contract to BATF. Neither identification nor detection taggants have been fully developed and tested; the detection taggant effort is less advanced than the identification taggant effort.

Legislation proposed in the U.S. Senate would make it unlawful (in the words of S. 333) "for any person or persons to manufacture any explosive material which does not contain both detection taggants and identification taggants," and would require that manufacturers and distributors keep records showing the distribution chain for each batch of explosive material that contains a separate identification taggant code. (Similar legislation has been proposed in the House of Representatives.) The Secretary of the Treasury would issue regulations implementing this requirement, and such regulations would be phased in as testing was completed and taggants become available in sufficient quantity.

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*The term gunpowder includes black and smokeless powders and pyrodex (a registered trademark of Hodgdon Powder Co.), a black powder substitute.

At hearings on this proposal, representatives of the explosives and gunpowder industries and others expressed opposition to the proposal on the grounds that:

- it is premature to consider explosives tagging legislation while development and testing of taggants have not been completed;
- taggants may be unsafe, since they would require adding a foreign substance to the explosive materials;
- a taggant program would be extremely costly; and
- a taggant program would not, in fact, have much utility for law enforcement.

Proponents of a taggant program have contended that:

- taggants are inert materials, no more unsafe than current additives to explosives and gunpowder;
- a taggant program need not be unduly costly; and
- bombings are extremely difficult crimes to prevent or solve using existing methods, and taggants would provide an extremely useful tool to law enforcement agencies.

The Senate Committee on Governmental Affairs has requested that OTA review the available data on explosive taggant technology and conduct an assessment which would address:

1. the safety of adding taggants to explosives;
2. the postdetonation survivability and recoverability of identification taggants;
3. the cost impact of a taggant program on the explosives industry and users;
4. the utility of a taggant program in law enforcement;
5. the effects on cost and utility of excluding certain explosive materials from the taggant program;
6. the removal of taggants from tagged explosives; and
7. alternatives to a taggant program.

The text of the request letter is included as appendix A.

The proposal to require that taggants be added to commercial explosives at the time of manufacture has aroused intense controversy. While OTA believes that this report will serve to narrow many of the areas of controversy, there are a number of issues on which the available data do not permit a scientifically conclusive finding. OTA has therefore made a number of judgments based on the available evidence where conclusive proof was lacking. In some cases these judgments, and the reasoning underlying them, have proved unpersuasive to one side or another in the controversy. Therefore, the final section of this chapter calls attention to the major areas in which one or more affected parties may disagree with the OTA findings.

Research Approach

In order to assess the impacts of a taggant program, a two-stage approach has been necessary. As the first stage, an analysis has been made of the safety and technical efficacy of the taggants at the current state of development, since cost and utility are moot points if the taggants are not safe and do not work. As the second stage, an assumption has been made that the taggants work and are safe and a parametric analysis of cost and utility made as a function of the specific implementation plan.

Due to severe time constraints, OTA did little original research. Instead, an intensive review of existing research was supplemented by discussions with manufacturers, distributors, and users of explosives and gunpowders, and with law enforcement personnel and experts on terrorism. Table 1 summarizes the major sources consulted.

In addition, OTA sent a questionnaire to approximately 650 members of the International Association of Chiefs of Police (IACP) asking them to assess the utility of taggants. (The IACP membership list was chosen because it constituted a broad cross section of the law enforcement community.) The questionnaire was sent to a random sample of the IACP members, and the low response rate (about 15 percent) probably created a bias towards those with interest in and knowledge of the subject. (A possible misconception may have been introduced by the explanatory material introducing the questionnaire, which inadvertently indicated that identification taggants could identify the last legal purchaser of explosives used in a bombing, rather than identifying a list of last legal purchasers.) The results of the questionnaire, interpreted with considerable caution, are integrated into the analysis in chapter VI and reported in detail in appendix B.

OTA also directed a series of tests on the recoverability of the 3M identification taggant. The Aerospace Corp. had conducted a large number of laboratory tests on the survivability of the 3M identification taggants, but the only information on the recovery of taggants under field conditions came from poorly documented demonstrations and training tests conducted by BATF, the Federal Bureau of Investigation, and other organizations. These tests, and others conducted by the Institute of Makers of Explosives, had produced conflicting and contradictory results. OTA planned and supervised a limited series of tests of the postdetonation recovery process of taggants from automobiles. The results of these tests are integrated into the findings, and described in detail in appendix C.

Table 1.—Major Sources of Information

Manufacturers
Explosives manufacturers (Du Pont, Atlas, Independent, Gulf, Hercules)
Gunpowder manufacturers (Hercules, Du Pont, Olin, Pyrodex)
Manufacturer of identification taggants (3M Co.)

Trade organizations
Institute of Makers of Explosives (IME)
Sporting Arms and Ammunition Manufacturers' Institute (SAAMI)

Consumer organizations
National Rifle Association (NRA)
National Muzzle Loaders Association (NMLA)

Organizations developing a taggant program
Bureau of Alcohol, Tobacco, and Firearms of the U.S. Treasury Department (BATF)
Aerospace Corp. (BATF contractor)

Organizations involved in taggant research
Management Sciences Associates
Institute for Defense Analyses
Lawrence Livermore Laboratories

Explosives and gunpowder distributors
B. F. Hodgdon
Tri-State Explosives

Gunpowder retailer
The Bullet Hole

Explosives users
Copper mines (Bingham Canyon open pit mine, Creek Fork underground mine)

Explosives users—continued
Coal Mine (Wabash Coal Co.)
Quarries (Tri-State, Rockville Crushed Stone)
Construction firm (Guy Atkinson)
Blasting contractor (Tri-State Explosives)

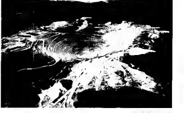
Law enforcement personnel
New York, N.Y.
San Mateo County, Calif.
Dallas-Fort Worth Airport, Tex.
Summit County, Ohio
Washington, DC

Experts on terrorists and terrorism
Experts from foreign and domestic law enforcement agencies
Writers on the subject (Dr. Ernest Evans, Dr. Rona Fields, Dr. Robert Kupperman)

Foreign law enforcement agencies
West Germany
England
Ireland
Israel

U.S. Federal agencies
Federal Bureau of Investigation
Federal Aviation Administration
Bureau of Mines
Department of Transportation
U.S. Army (Corps of Engineers, Criminal Investigation Division, Development and Research Command)

SOURCE: Office of Technology Assessment.



Explosives are utilized extensively at the Bingham Canyon open pit copper mine

Some Project Limitations

There are three general limitations to the completeness of this analysis of the proposal to legislate the use of taggants in explosive materials. **The primary limitation is caused by the preliminary nature of the taggant research—**much data are simply not available. Additional information is required on all aspects of the analysis—technical efficacy, safety, cost, and utility. Table 2 summarizes the research conducted to date.

Preliminary safety testing has been conducted on only a portion of the materials to which identification taggants would be added, and compatibility testing has barely begun with detection taggants. Evidence has been found of reactivity (using high taggant concentrations at elevated temperatures) between the 3M identification taggants and one type of smokeless powder as well as one booster material. This reactivity creates a presumption of incompatibility. Until this presumed incompatibility is resolved, taggants cannot be safely added to these explosive materials. Resolution of the problem may result in significant changes in the taggants, requiring a new set of compatibility tests and perhaps changing the basis of the cost analysis. If the problem is resolved, more data still need to be generated. The lack of data on long-term effects, in terms of safety, stability, and performance, especially on products such as gels and slurries, is par

Photo credit: U.S. Department of the Treasury

Photograph of automobiles utilized in the OTA taggant recovery test

Table 2—Current State of Taggant Research

	Identification taggants		Detection taggants
	Compatibility	Survival recovery	Compatibility
Cap sensitive	Preliminary finished	Preliminary finished	Preliminary underway
Boosters	Preliminary underway-compatibility problem identified	Preliminary underway	Testing initiated
Detonators	Preliminary underway	Preliminary underway	Testing initiated
Blasting agents	None	None	None
Detonating cord	None	Testing initiated	Testing initiated
Black powder	Preliminary finished	Preliminary underway	Preliminary underway
Smokeless powder	Preliminary underway-compatibility problem identified	Preliminary underway	Testing initiated
Military explosives	None	None	None

[a] As of mid-January 1980.

SOURCE: Office of Technology Assessment.

tionally important. As a result of the novelty, not even preliminary indications of safety are possible at this time, much less the demonstrations necessary before a taggant proposal could safely be implemented.

While preliminary research has been conducted on the survivability and nonreactivity of the 3M identification taggants, only a portion of the explosive materials which might be tagged was tested, and that research is poorly documented. Hundreds of possible detection taggants have been screened to yield five candidate materials, but detailed testing of the properties of these materials is barely underway. Similarly, three candidate detection sensors have been identified and limited laboratory testing of prototypes or breadboard models is completed. Methods of air sampling are also at a preliminary stage. Thus, estimates of taggant efficacy can only be made on the basis of preliminary data.

As a result of the pilot test program, reasonable data are available for the analysis of the cost impact of adding taggants during the manufacture of cap-sensitive high explosives, at least for those companies which participated in the program. The data, however, on the cost impact of adding taggants during the manufacture of the other types of explosive materials (for example, gunpowders) are less adequate. While firm estimates of the cost of unencapsulated identification taggants are available from 3M under a variety of implementation conditions, little data are available for the cost of encapsulated identification taggants (a more likely baseline case) or for the cost of detection taggants. Only the grossest estimates have been made of recordkeeping costs, and the estimates by both the proponents and opponents are open to some questions of objectivity. Rule-of-thumb engineering estimates have been made for the candidate sensor systems costs, but the accuracy of these estimates cannot be very precise as neither production rate nor production cost specifications have been established.

So far, identification tagging of explosives has played a part in only one criminal case that has reached a conclusion. (Those investigating and prosecuting the case considered evidence from taggants very helpful.) Quantification of the utility of taggants (identification as well as detection) is therefore simply not possible, particularly given the inadequacy of bombing statistics. Experience with the date shift code (which facilitates tracing of undetonated explosives) provides useful data, as does the experience of foreign countries, but the available information on the utility of taggants is preponderantly qualitative in nature.

A second general limitation to the completeness of the analysis, imposed by constraints on available time and resources, **is that only a limited sample of the population concerned with the study could be contacted.** As a result, cost data derived from a detailed analysis of one or two companies have been assumed to be representative of an entire segment of an industry, such as underground coal mining or retail sale of gunpowders. Similarly, processes for adding taggants, reworking of waste material, quality control, compatibility testing, and storage, which are applicable to a segment of the manufacturers of explosive materials, have been assumed to be universal for the purpose of generating cost estimates. A more serious manifestation of the limited sample size is that in-depth discussions of the utility of identification and detection taggants to law enforcement and security personnel could only be held with a small number of organizations. As the terrorist threat varies considerably from one part of the country to another, it is difficult to generalize the results of these discussions.

The third limitation on the analysis is caused by the language of the draft legislation, S. 333. The bill calls for tagging of all explosive materials, which does not appear practicable if the phrase is strictly interpreted to include the tagging of blasting agents that are mixed the same day they are detonated, and otherwise offers no guidance for the implementation regulations which the Secretary of the Treasury would promulgate.

SUMMARY OF FINDINGS

The assessment distinguishes between an evaluation of the present state of development of taggants and a projection of the cost and utility of a taggant program if and when the necessary development and testing are successfully completed. A detailed evaluation of the development status of the identification and detection taggants is contained in chapter III. A crucial factor in the development status evaluation concerns the safety of adding taggants to explosives; the safety and general compatibility analysis is contained in chapter IV. OTA then separately evaluated the cost and utility of a program to add taggants to commercial explosive materials. For this analysis, it was assumed that the baseline identification and detection taggants had successfully completed the development process, including a resolution of the safety issues. These analyses are contained respectively in chapters V and VI. Details of these and other findings are given in chapter II. The principal findings are shown in table 3 and briefly summarized below.

Taggant Utility

Assuming for purposes of analysis that stability questions are successfully resolved and that technical development is successfully completed both identification taggants and detection tag

Table 3.—Summary of Current Status of Taggants

	Identification taggants	Detection taggants
Safety		
Dynamites, gels, slurries	No change in sensitivity, stability	No reported data, testing initiated
Black powder	No change in sensitivity or stability	No reported data, testing initiated
Smokeless powder	Reactivity with Hercules powder observed; incompatibility presumed	No reported data, testing initiated
Booster materials	Reactivity with Composition H observed; incompatibility presumed	No reported data, testing initiated
Blasting agents	No data	No data
Performance	Limited testing	No data
Survivability		
Normal use conditions	Yes	N/A
Fire	Probable	N/A
Confinement	Insufficient data	N/A
Recoverability		
Field recovery	Probable if survive	N/A
Field decoding	Unlikely	N/A
Laboratory decoding	Almost all conditions	N/A
Sensor development	N/A	Early stages
Utility		
Low-value targets	Little	Virtually none
High-value targets, no countermeasures	High	High
High-value, including countermeasures	High due to increased data	High for all but most sophisticated bombers

Cost ($ million/year)	Identification	Detection	Both
Low-level program (ID tag made for each product changed each year, ANFO excluded)ᵃ	$ 8	$22	$30
Baseline program (ID tag made for each product changed for each shift, ANFO excluded)	20	25	45
High-level program (ID tag changed for each 10,000-lb batch, ANFO included)	25	65	90

N/A—not applicable.
ᵃThese programs are defined in detail in ch. VI.

SOURCE: Office of Technology Assessment.

gants would be useful law enforcement tools against most terrorist and other criminal bombers. Their utility against certain types of bombers would probably be quite high. Their utility against the most sophisticated of terrorists and professional criminals is open to question.

- **Data on the number and kinds of bombings committed are dispersed and inconsistent.** Table 4 gives an idea of the magnitude of the problem. Its significance is discussed in chapter II and the derivation of the figures in appendix F. OTA diligently sought to find or reliably derive data from which one could calculate the number of bombings that a taggant program would solve or deter, and found this an impossible task.
- **Criminal bombings are committed by a wide range of perpetrators, including both individuals and groups.** It is helpful to group criminal bombers into four categories which differ greatly in their motivation, skill, training, resources, and ability to respond to a changing enforcement environment. They are defined and their proportions estimated in table 5. Note that despite the tendency for some groups to claim credit for a bombing, a motive was established for only 23 percent of the bombings reported to BATF in 1977 and only 36 percent in 1978. Table 5 is based on the assumption that the distribution of motives was the same for the numerous incidents in which law enforcement officials were unable to assign a motive.
- **Identification taggants would facilitate the investigation of almost all significant criminal bombings in which commercial explosives were used.** Due to the need for laboratory involvement in the taggant recovery process, the taggants would probably not enter into investigations of bombings that produce no casualties and little property damage.
- **Detection taggants would be very effective in protecting those high value targets where protection by detection taggant sensors is feasible.** The improvement in protection of such potential targets would be quite substantial. However, most criminal bombings take place against targets that are unlikely to be protected by detection taggant sensors.
- **Adding taggants to blasting agents would have some utility, but the incremental utility would be small compared to the utility of tagging cap-sensitive high explosives, gunpowders, and detonators (and the incremental cost would be high).** A taggant program that did not include gunpowders would be of relatively limited utility, as pipe bombs filled with gunpowder are used in a substantial number of

Table 4.—Minimum Bombing Incidents Statistics Summary[a]

	BATF		FBI	
[illegible]	1977	1978	1977	1978
Explosive bombings, number	1,375	[illegible]	867	768
Undetonated explosive bombs, number	388	257	119	75
Incendiary bombings, number	330	446	240	343
Unignited incendiary bombs, number	[illegible]	71	66	79
Criminal accidents, number		31	67	—	—
Property damage from bombings (millions of dollars)[d]	$11	$8.7	$9	$9
Injuries	550	491	162	135
People killed by bombings[c]	38	28	22	18

a BATF reported [illegible]

c Includes both explosive and incendiary bombings [illegible]

d Actual value probably considerably higher [illegible]

SOURCE: BATF, Explosives Incidents Report; FBI, Uniform Crime Report: Bomb Summary 1978. See app. F for a discussion of the derivation of these figures.

Table 5.—Proportions of Bombings Attributed to Groups of Perpetrators (average for years 1974-78)

Bomber type	Characteristics	Percentage of bombings	Estimated number in 1978a
Terrorists	Highly motivated, varied skill levels, act in groups, continuing involvement	12	117
Criminals	Varied motivations, varied skill levels, act alone or in small groups, repeated activities, specific targets	[illegible]	[illegible]
Mentally disturbed	Highly motivated, poorly trained, act alone, seldom repeat crimes	36	340
Vandals and experimenters	Limited motivation, poor training, limited resources, do little damage	36	340

[a] See app. F for derivation of these estimates.

SOURCE: [illegible]

bombings. If only high explosives were tagged, criminals could shift to pipe bombs rather easily.

- **The utility of both identification and detection taggants would be decreased because some bombers would take countermeasures.** Explosives experts have suggested a number of possible countermeasures to the proposed taggant technology which would be available to those bombers with the requisite knowledge and resources. Most available countermeasures would increase the risk to the bomber of personal injury or arrest or decrease the reliability of the bomb. Law enforcement officials and experts on terrorism agree that most bombers would not utilize the available countermeasures. A taggant program would retain substantial utility even though some criminal bombers would attempt countermeasures, and these countermeasures would be effective whenever they were carried out with sufficient knowledge and skill.

- **The utility of taggants to law enforcement personnel is not adequately quantifiable,** due to the paucity of data on taggants or similar control mechanisms, the difficulty of analyzing the currently collected statistics on bombings, and the fact that it is difficult to quantify how much any single clue adds to an investigation or prosecution. Generally speaking, law enforcement techniques are seldom subjected to cost/benefit analysis, and the data which exist do not lend themselves to such effort. Similarly, OTA was unable to quantify the deterrent effect taggants may have, although the apparent effectiveness of airport screening procedures in reducing the number of hijacking attempts suggests that detection taggants may have a considerable deterrent value.

Taggant Cost

The cost of a taggant program would vary enormously depending on the nature of the program. Costs are likely to be reasonable if and only if any taggant legislation requires regulations to be written in a way that weighs costs against considerations of law enforcement utility.

- **A low-level taggant program,** in which a unique taggant species would be used to identify each year's production of a specific product and 900 detection sensors would be deployed, **would cost $30 million per year.**

- **A "baseline" program identified by OTA (described in detail in ch. V) would cost approximately $45 million per year, adding** approximately 12 percent to the cost of cap-sensitive explosives and slightly under 8 percent to the cost of gunpowder. Cap-sensitive high explosives, boosters, detonators, detonating cord, and gunpowder would be tagged. A unique taggant species would be used for each shift's production of each product and size. Fifteen hundred detection sensors would be deployed. The bulk of this cost would eventually fall on users of explosives and on users of products produced with the aid of explosives; the costs of detection taggant sensors would presumably be borne by the owners or users of protected facilities. It is not expected that costs of this magnitude would lead to any major shifts in the patterns of production and use of explosives.

- **Separate baseline identification and detection taggant programs would cost approximately $25 million per year each,** excluding public overhead costs.

- **A high-level program,** in which a unique taggant would be used for each 10,000-lb batch of explosives or 2,000-lb batch of gunpowder, in which blasting agents would be tagged, and in which 6,000 detection sensors would be deployed, **would have an estimated cost of $258 million per year.**

- **The cost estimates assume that the taggant material costs do not differ appreciably from current estimates for mass-produced taggants.** Chapter V discusses the causes and the extent of the uncertainties surrounding these cost estimates.

Technical Development

The development of taggants is not yet complete. Further developmental effort, particularly resolution of the questions regarding the stability of smokeless powder and cast boosters to which taggants have been added and successful completion of a variety of tests, would be required before it would be appropriate to begin adding taggants to nonmilitary explosives.

- **The identification taggants developed by 3M appear to survive the detonation of commercial explosives under ideal conditions.** Confinement and fire may adversely affect survival although test data is very limited. Recovery of the taggants appears to be a function of the specific incident conditions (weather, type of target, bombing activity) as well as the timing and nature of the bomb scene investigation. A trained team can probably recover debris from which a laboratory can separate taggants under most incident conditions.
- **There is little basis for judging whether the detection taggant system,** based on machine sensing of microencapsulated vapors, which appears to show promise under laboratory conditions, **would function reliably under conditions of mass production and field use,** or how soon such a system would be available.

R

Safety

The tests so far conducted create a presumption that there are no incompatibilities between the 3M identification taggant and dynamites, slurries, gels, emulsions, or black powder. Nevertheless, a full-scale qualification program is necessary before taggants can be added to all such materials.

- **The addition of 3M identification taggants to one brand of smokeless powder (Herco®*) and one variety of booster material (Composition B) produces a chemical reaction at elevated temperatures and high taggant concentrations.** The taggants must be considered incompatible with such explosives unless or until 1) the composition of the taggant is changed in a way that eliminates this chemical reaction, or 2) a determination is made that the reaction takes place only under circumstances that can be prevented from arising in commercial production, distribution and use. If the incompatibility remains, then Congress could, if it chose, require that these particular explosives either be themselves modified, withdrawn from the market, or granted an exemption from tagging. (OTA believes that exemption of smokeless powders would significantly diminish the utility of a tagging program; exemption of cast boosters would diminish the utility to a somewhat lesser extent.) If compatibility is established, completion of a qualification program would still be necessary.
- **There is little evidence regarding the safety of detection taggants, or of the combination of identification and detection taggants, as testing has only recently been initiated and no results have yet been reported.**
- **Analysis, and the limited testing so far conducted, indicate that the performance of explosive material would not be degraded by the addition of taggants.** However, preliminary tests suggest that abnormally high concentrations of taggants might decrease the ballistic performance of smokeless powder. Testing, including long-term effects, would be necessary, however, before the question could be fully resolved.

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*A registered trademark of Hercules, Inc.

CONTINUING CONTROVERSIES

Some of OTA's findings have been challenged by one or more of the participants in the controversy that surrounds the proposal to require that commercial explosives be tagged. The nature of these challenges is outlined here.

Significance of Compatibility Testing to Date

A large number of tests have been carried out to determine whether the 3M identification taggant is compatible with commercial explosives. More tests are required, and the Aerospace Corp. (under contract to BATF) is sponsoring a continuing testing program. The tests completed to date are described in chapter IV.

OTA found that the testing done to date creates a reasonable presumption that the 3M identification taggant is compatible with dynamites, gels, slurries, emulsions, and black powder. On the other hand, there is evidence of increased reactivity, and thus a presumption of incompatibility, with at least one form of smokeless powder and at least one cast booster composition. It is not yet possible to arrive at presumptions about the compatibility of the 3M taggant with blasting caps or detonating cord, or about the compatibility of detection taggants with any commercial explosive. OTA further found that even for products such as dynamites where no evidence of incompatibility exists, further testing is required before it can be definitely concluded that taggants are compatible with, and can safely be added to, all such explosives.

The Aerospace Corp. takes the view that the compatibility tests with dynamites, gels, slurries, emulsions, and black powder generally are sufficient to permit implementation of a program to tag these substances. Aerospace recognizes that there is a need for Mine Safety and Health Administration approval of tagged permissible dynamites, that final qualification of production-line 3M taggants must be made to ensure that they match those used in the qual tests, and that the black powder ballistics testing should be reviewed and possibly augmented. However, Aerospace points out that while not every test has been conducted with every brand of every explosive, the program successfully carried out was designed by industry and was considered sufficiently thorough so that several major firms were willing to distribute pilot quantities of tagged explosives through their normal commercial distribution channels. With regard to smokeless powders and cast boosters, Aerospace takes the view that no safety hazard has been demonstrated, but that the failure of the tagged explosive to pass certain extreme tests means that compatibility has yet to be demonstrated and the possibility that some changes will be required to ensure safety cannot be ruled out.

Representatives of the explosives industry take the view that taggants cannot be considered compatible with explosives until all the testing that ought to be carried out has been successfully completed. They maintain that until safety has been conclusively demonstrated, it would be premature to consider whether to legislate a requirement that commercial explosives be tagged. Explosives industry representatives also make a distinction between the pilot program so far carried out and normal commercial production. They maintain that the tagged explosives manufactured under the pilot program received unusual care and attention during the manufacturing process and were distributed to a limited number of selected distributors. The manufacturers also believe that the terms of the pilot program relieved them of liability for accidental explosions due to taggants, a point which the Aerospace Corp. contests. Some explosives industry representatives take the view that the failure of the mixture of taggants with one brand of smokeless powder and one cast booster composition to pass one safety test means that the 3M taggant should be viewed as unsafe unless and until it is redesigned, and point out that any such redesign would require repeating all other tests previously carried out.

Countermeasures

It is clear that it would be possible for terrorists or other criminals to take measures to defeat the impact of a tagging program, by making or acquiring untagged explosives. OTA found that such countermeasures would require a considerable degree of technical knowledge and skill, and that in most cases countermeasures would either require the commission of an additional crime (with some added risk of apprehension) or else manufacturing or modifying explosives in a way that would risk either a premature explosion or a misfire of the bomb. **The law enforcement experts whom OTA consulted predict that many terrorists and other criminals would probably not avail themselves of countermeasures that were theoretically available to them.**

Representatives of the explosives industry take the view that one should assume that an available countermeasure will in fact be employed. They point out that the most sophisticated bombers, who are most likely to be willing and able to employ countermeasures, are those which may pose the greatest threat. They fear that a taggant program would fail to be effective because of widespread use of countermeasures, and that law enforcement officials would then wish to counter the countermeasures by extending the range (and hence the cost) of the taggant program.

OTA has noted a consistent pattern of disagreement on this point. Experts in the explosives industry and Government explosives experts almost unanimously believe that countermeasures exist which would enable bombers to evade the effects of a taggant program, whether the countermeasures take the form of removal of taggants from tagged explosives, use of untagged blasting agents, theft of explosives, fabrication of "homemade" explosives or use of incendiary devices. Law enforcement experts, and experts on terrorists and terrorism, almost unanimously believe that most bombers, including terrorists, would fail to take the steps necessary to evade a taggant program, even though the necessary equipment and knowledge is not too difficult to obtain. A possible analogy is the effectiveness of the program to counter aircraft hijacking: since that program began, thousands of weapons have been detected each year while there have been no cases of aircraft hijacked with weapons smuggled onboard, despite the fact that mechanisms can be purchased for smuggling weapons past the screening apparatus. OTA believes that while countermeasures to a taggant program would be available and would be effective if correctly used, most bombers would not make effective use of such countermeasures. **OTA believes that taggants, if successfully developed, could have significant law enforcement utility even if some terrorists or other criminals successfully employed countermeasures.**

Blasting Agents (ANFO)

Blasting agents are the most widely used type of commercial explosive; the most common type of blasting agent consists of mixtures of prilled ammonium nitrate and fuel oil; these explosives are collectively known as ANFO. ANFO can be mixed in a factory or mixed directly at the site where blasting is to take place. Ammonium nitrate fertilizer can be mixed with ordinary fuel oil to create a rather insensitive ANFO.

Because of the very large volume of ANFO that is used commercially, a tagging program which included ANFO would be substantially more costly than one from which ANFO was excluded. Chapters II and V present detailed information on this point. One of the reasons for the wide gap between BATF and the explosives industry cost estimates for a tagging program is that the industry read the draft legislation (S. 333) as requiring that ANFO and other blasting agents be tagged, while BATF was planning for a taggant program that would not include ANFO.

Representatives of the explosives industry have taken the position that exclusion of ANFO would greatly diminish the law enforcement utility of a taggant program, because bombers could and would use untagged ANFO in place of tagged cap-sensitive explosives or tagged gunpowders. OTA believes that it is n deed the case that an effective bomb, suitable for almost all criminal or terrorist purposes, can be manufactured from ANFO if the criminal has adequate time, skill, knowledge, and motivation. **The critical issue about which judgments differ is the extent to which terrorists and other criminals would in fact make use of ANFO bombs if other commercially available explosive materials were tagged.**

OTA does not consider it appropriate to describe here how one would go about manufacturing an ANFO-filled bomb. The process involves more steps, a greater number of materials and components, and more opportunities for error than a bomb made from a cap-sensitive explosive; however, it would be easier and safer than fabrication of a bomb from raw chemicals. The ANFO commercially available in the United States would not be reliably detonated by an ordinary detonator (#8), even in a pipe bomb. ANFO can be readily detonated by using a small high-explosive booster, but such boosters would be tagged, and a large booster or several small ones would make an efficient bomb without the use of ANFO. ANFO can also be detonated using materials that would not be tagged (if the bomber knows how to use them), but an ANFO pipe bomb is substantially harder to detonate than a smokeless powder pipe bomb or a stick of dynamite.

Photo credit: U.S. Department of the Treasury

A pipe bomb. Such bombs are normally filled with black and smokeless powder, but a bomber with sufficient knowledge and skill could use ANFO

At the present time, ANFO is seldom used in pipe bombs despite the fact that it is cheaper and, if properly detonated, considerably more energetic than smokeless powder. Whether the tagging of cap-sensitive high explosives and powders would in fact lead many criminals to switch to the use of ANFO is a question that cannot be answered with certainty. **However, as in the case of other countermeasures, OTA has found that explosives experts tend to expect that criminals would switch to ANFO, while law enforcement experts and experts on terrorism tend to doubt that this would happen in many cases.**

Survivability and Recovery of Taggants

The testing done to date on the conditions under which identification taggants would in fact survive an explosion, and surviving taggants could in fact be recovered, is not adequate to sustain firm conclusions. Much of the available data is anecdotal rather than systematic. Part of the problem is that it is difficult to arrange for testing under realistic but controlled conditions. Faced with inadequate and somewhat contradictory data, particularly with respect to the recovery question, OTA arranged for a very limited test program to supplement the previous tests; appendix G reports on the effort.

OTA feels that prior testing supports the presumption that taggants would probably survive most bomb detonations under most conditions. However, survivability decreases with the size of the explosive charge and its power. The survivability of individual taggants in large explosive charges or in extremely powerful explosives (such as booster material and military explosives) has not been demonstrated. Pressed pellets, fabricated from the individual taggants, do survive the detonation, but recovery has not been adequately demonstrated, and compatibility tests on pellets remain to be accomplished. **OTA found that the taggants surviving most bombs could probably be recovered under most conditions. However, field investigators might well find it impossible to separate the taggants from the debris, identify in-**

dividual taggants, and read the codes in the field; instead the field team would have to gather debris likely to contain taggants, and a laboratory could thereafter separate and read the taggants. Such a laboratory need not be elaborate, and could be installed in a truck if onsite taggant reading was considered desirable.

BATF maintains that, on the contrary, the 3M identification taggant can be recovered and read in the field by investigators who have received a reasonable amount of training.

Some industry representatives maintain that there is considerable doubt as to whether taggants would actually survive and be recovered from a bomb. Such doubts should, if they hold, be cleared up before attempting to reach any judgment about the utility of an explosives tagging program.

Development Time

OTA believes that the further development and testing that would be required before an identification taggant program could be implemented are likely to take until 1983. If an identification taggant program were legislated early in 1980 it would be at least late 1984 before all commercial explosives could be manufactured with taggants. Even if the sensor development and detection taggant programs are successful, OTA feels it would be at least 1985 before full implementation could occur. BATF maintains that these times are too pessimistic.

CONGRESSIONAL OPTIONS

Given the present state of development of taggants, OTA's data and analysis appear to be consistent with any of three possible courses of action. (No significance is intended in order of listing.)

- **Pass legislation requiring taggants, and** set up a procedure to determine if and when the technical development and testing have progressed to a point where implementation can begin. Given the active involvement of BATF in the development of taggants, it may be inappropriate for the implementation decision process to reside in the Treasury Department.
- **Defer legislative action on taggants, but encourage BATF to continue taggant development,** with a view to consideration of legislation when development and testing are complete.
- **Take no legislative action on taggants, and encourage** the executive branch to search for other ways of improving the effectiveness of law enforcement against terrorist and other criminal bombers.

Chapter II

DETAILED FINDINGS

Chapter II- DETAILED FINDINGS

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Chapter II

DETAILED FINDINGS

This chapter presents the findings of the study in some detail, along with a sketch of the data and analytic methods used to arrive at them. The full analyses on which these findings are based are found in the subsequent chapters and the appendixes.

The analysis proceeded in two stages, which were conducted simultaneously. The first stage assessed the technical efficacy of the taggants and their compatibility with explosive materials. Definitive judgments on these points must await the results of further technical development and testing. The second stage estimated the cost and law enforcement utility of taggants, assuming that taggants can be made which work and are safe. It should be clearly understood that a taggant program is only appropriate if all the conditions are met. It must be technically sound, it must be safe, it must have value for law enforcement, and the costs must be reasonable in the light of this law enforcement value.

The analysis and discussion of technical efficacy and safety were conducted as if it had been established that taggants are useful in relation to their cost. The analysis and discussion of cost and utility were conducted as if it had been established that taggants work and are safe.

Because a variety of implementation plans are possible, costs and utility are evaluated parametrically in order to show how the choices made in writing regulations would lead to variations in cost and law enforcement value.

OVERVIEW OF THE PROBLEM

In order to appreciate the potential benefits and shortfalls of a tagging program, it is necessary to understand the magnitude of the current and projected future bombing threat as well as the processes involved in the manufacture, distribution, and sale of the various explosive materials.

The Bombing Threat

Both the Federal Bureau of Investigation (FBI) and the Bureau of Alcohol, Tobacco and Firearms (BATF) are the national bombing data information centers which collect statistics on bombings and other explosive incidents. The data are not consistent between the two centers, however, and many bombings are not reported to either center. The formatting of the data, and the lack of updating procedures, make accurate analysis difficult. Appendix F explains in some detail which data sources were used and why. While BATF and FBI data differ in the absolute values (e.g., number of bombings in a year), both sets of data support the OTA findings. Most tables in this report make use of BATF data because its format appeared more amenable to analysis.

The BATF 1978 Explosives Incidents Report includes over 3,000 incidents for both 1977 and 1978. The incidents include anonymous threats, seized and recovered explosives, and hoaxes, as well as actual explosive and incendiary bombings. Of these incidents, 1,377 represented actual explosive detonations, accidental detonations by criminals, or recovered bombs that failed to detonate in 1977, with

1,250 the corresponding number for 1978. At least 953 of these in 1977 and 787 in 1978 represent actual detonations of explosive bombs against substantial targets (mailbox and open-area bombings are not included).

During 1977, BATF estimates that 38 people were killed and 190 wounded by explosive and incendiary bombs, while the numbers in 1978 were 23 and 185, respectively. Due to the way initial estimates of property damage are made and the lack of updating, only the crudest property damage estimates can be made. There was at least $10 million in direct property damage due to explosive and incendiary bombs in 1977, and at least $17 million in 1978. In 1977, 35 of the 38 reported deaths and 20 of 23 reported in 1978 were from bombings against vehicles, residences, and commercial establishments. Similarly, about 69 percent of the injuries from bombing of known targets in 1977 and about 70 percent in 1978 were caused by bombings of these three types of targets. The 1977 and 1978 statistics are summarized in table 6 and discussed in more detail in appendix F.

The available data do not enable any conclusions about trends in the bombing threat. Both the number of incidents and the extent of deaths, injuries, and property damage vary from year to year and from data base to data base. Management Sciences Associates (MSA) conducted a detailed study of the data in the 5 years from 1972 through 1976 without discovering any significant trends. Many experts on terrorism believe that the United States may experience an increase in bombings, particularly catastrophic bombings, in the years ahead. However, this belief is based on an assessment of U.S. vulnerability to bombings and the observation that the United States has recently had less of a terrorist problem than other developed countries; there is no evidence that this increased threat has materialized. In looking at bombing statistics, one should bear in mind that a single incident involving an aircraft exploding in flight could produce more deaths than have occurred in any year to date.

Data on the types of fillers used in bombs are also not consistent between the FBI and the BATF data banks. It is instructive to look at two BATF data sources, however, as shown in table 7. The second column represents 1978 data for the fillers identified in the field for all explosive bombs that were detonated, devices recovered undetonated, and criminal accidents. The first column represents 1978 data for only those fillers that were identified in the laboratory from postdetonation analysis. The third column averages the first two. In both cases, black and smokeless powders and cap-sensitive high explosives all occur with high frequency. Table 8 shows a breakout of the minimum number of significant bombing incidents, deaths, and injuries occurring during 1978 by explosive material fillers. The average column in table 7 was multiplied by data on

Table 6.—Minimum Bombing Incidents Statistics Summary

Item	BATF 1977	BATF 1978	FBI 1977	FBI 1978
Explosive bombings, number	1,037[a]	792	867	758
Undetonated explosive bombs, number	318	337	111	100
Incendiary bombings, number	334	446	248	340
Unignited incendiary bombs, number	61	7[illegible]	65	79
Criminal accidents, number		2	67	[illegible]
Property damage from bombings, millions of dollars	$ 10	$ 17	$ 1	$ 9
Injuries	190	185	160	135
People killed by bombings[b]	38	23	22	30

[a] BATF reported 1,177 total incidents in 1977 and [illegible] total incidents [illegible]
[illegible]
[b] [illegible]
[illegible]

SOURCE: [illegible]

Table 7.—Identified Explosive Fillers Used in Bombs

	Lab identified fillers 1978	Field identified fillers 1978	Average
Black powder	30%	21%	25.5%
Smokeless powder	14	9	11.5
Military	2	7	4.5
Cap sensitive	28	34	31
Blasting agents	—	1	.5
Chemicals			.5
Others	26	21	23.5

See app. F for definition of these numbers.

SOURCE: BATF data.

Table 6—Bombing Casualties and Damage in 1979 by Type of Bomb

Filler material	Number of bombings against unoccupied targets	Deaths	Injuries	Property damage $ millions
All fillers	1,076	23	185	$17.2
Incendiary	436	3	3	9.7
Black powder	245	4	8	.2
Smokeless powder	52	3	23	.2
Military explosives	39	1	7	—
Cap sensitive	270	7	26	3.3
Other		3	48	2.4
Unknown		3	37	7.4
Total for those fillers which would be directly tagged[b]	570	15	68	3.7

[a]Value probably higher due to lack of data update.
[b]Cap-sensitive explosives, black powder, and smokeless powder would be tagged.

SOURCE: BATF data. See app. F for a derivation of these figures.

total bombing to generate the table 6 estimates. See appendix F for details.

Manufacturer to User Chain

Explosives

Approximately 4 billion lb of explosives are manufactured and used annually in the United States. Of this amount, approximately 600 million lb are standard explosives and 3.4 billion lb are blasting agents (primarily ammonium nitrate-fuel oil mixtures). Of the 600 million lb of standard explosives, about half are cap sensitive (will reliably be detonated by a #8 detonator)—dynamites, emulsions, gels, and slurries, and about half are noncap-sensitive gels, slurries, and emulsions. Most of the standard explosives are manufactured in a plant, packaged in cartridges, and shipped either directly to a large user such as a coal mine or to a distributor, although some are processed essentially onsite. Some of the blasting agent products are prepared by a manufacturer and sold in packages; some are prepared by a manufacturer and sold in bulk (tanker truck), while some are mixed onsite and used the same day they are prepared.

Standard explosives are made by mixing together the fuel and oxidizer ingredients and feeding the mixed product into the final cartridges by a batch, semicontinuous, or continuous process. In a batch process, the ingredients for a particular batch are first mixed and then packaged before another batch is started on that production line. In a semicontinuous process, the mixed batch is fed into an intermediate hopper from which packaging takes place while another batch is mixed in parallel to the packaging of the last batch. In a continuous process, the material is continuously added to the mixer, processed, and packed in a continuous flow.

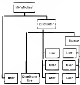
If taggants were added to standard explosives, they would be added at the mixing stage. Taggants could also be added to packaged or bulk form manufactured blasting agents at the mixing stage. If the ammonium nitrate used to make onsite-formulated blasting agents were to be tagged, identification taggants could be added during the prilling process, while detection taggants, which are not batch specific, could be added with the fuel oil.

Boosters are generally fabricated by pouring a molten high-energy cap-sensitive explosive such as TNT into containers. Taggants could be added during the cooling process of the explosive.

Detonators and detonating cord are manufactured products in which the product is built up around an explosive core in an assembly line process. In both cases, the taggants would be added during the assembly process, rather than directly in the explosives.

All of the products have a similar flow from manufacturer to ultimate user, as shown in figure 1. Some of the products are sold directly by the manufacturers to large users, such as a mine or large construction company. Such sales may represent an entire day's production. The rest is sold to distributors who may buy portions of several production batches, entire batches, or even several batches. The distributors in turn sell to retail stores, supply explosives directly to some users (such as a quarry or construction site) and may also do explosive contracting themselves. A particular uniquely tagged batch of explosives may therefore go directly to one user, may go to one distributor or may be sold to a number of users and distributors. From the distributor it may again go to one of several users, sometimes with a further distribution level (retailer) involved. A list of the ultimate purchasers of one specific batch of explosives could therefore contain one name or up to a hundred names for a worst case example, although generally the number would be at the low end of that range.

Figure 1.—Explosive Distribution Chain



SOURCE: Office of Technology Assessment

Gun powders

The manufacture and distribution processes for gun powders are significantly different from those of explosives. Approximately 2 1/2 million lb of black powder and 20 million lb of smokeless powder are produced for commercial use each year. Most of the smokeless powder is used in fixed ammunition for rifles, pistols, and shotguns, would not be sold to users as an end product, and would not be tagged under S. 333. Approximately 5 million lb per year would be sold to the end user primarily for handloading of ammunition. Of the black powder production, approximately 2 million lb are used as an intermediate product in the manufacture of fuzes and other finished products and would not be tagged; approximately 400,000 lb per year are sold for use in muzzle-loading guns and would be tagged if a taggant program were legislated.

The basic process for the manufacture of gunpowders involves the following steps:

- mixture of ingredients, which may include the raw ingredients as well as surplus and reworked powders;
- granulation, where the dough is extruded, chopped, or otherwise granulated to form the various grains;
- screening of grains into designated sizes; and
- blending of various batches to get the desired ballistic characteristics.

In the smokeless powder manufacturing process, nitroglycerine, nitrocellulose, and other additives are combined to make various grades before the blending process. Smokeless powder grades therefore differ due to size differences and composition differences (various amounts of nitroglycerine), while black powder and black powder substitutes such as Pyrodex* vary only by grain size. In a given grade of powder, variations in density and other fluctuations during the manufacturing process can cause considerable variations in the ballistic properties of the final powder. As the handloader generally has no means of controlling his ballistics other than the weight or volume of powder added, the ballistic properties of a particular grade of powder must be carefully controlled by blending. A given brand name product may therefore contain parts of several batches, blended like brandy to give the desired ballistic properties. Several sequential blending operations may be necessary before the product meets the required specifications. If the ballistic properties of a particular batch or blended lot are too far off, the material must be reprocessed or used for something other than hand loading.

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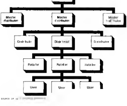
*A registered trademark of Pyrodex Co.

If taggants are added to gunpowders, they may have to be added at different stages in the manufacturing process for different manufacturers, due to the differences in blending and reworking processes. As an example, at one smokeless powder factory that makes powder for both handloading and fixed ammunition, taggants could be added during the blending stage; blended batches that were still not satisfactory could be used for fixed ammunition. At another factory, due to their large rework factor, an additional taggant mixing stage might be necessary. For some products, it may be possible to add taggants to the dough, although this may affect the granulation process and present blending problems.

The distribution network from gunpowder manufacturers to users differs markedly from that of explosives, since there is a very large number of ultimate users, each of whom consumes a small amount of powder. The network is shown schematically in figure 2. The manufacturer has several master distributors, each of whom supplies a number of distributors. Each distributor supplies a number of retailers, who sell the product, often in pieces as small as 1 lb. A 2,000-lb uniquely tagged batch of product "A" may therefore ultimately be sold to over a thousand customers. Not only does this produce a much larger list of last legal purchasers, but considerably more record keeping would be involved at the retail level.

Figure 2.—Gunpowder Distribution Chain



SOURCE: [illegible]

TECHNICAL EFFICACY

The issues to be addressed here include the survivability of the identification taggants and the status of the detection taggant materials and sensors. A detailed discussion of the research program related to technical efficacy is in chapter III; chapter IV discusses in detail the research related to safety.

The identification taggants developed by 3M appear to survive the detonation of commercial explosives under ideal conditions. Confinement and fire may adversely affect survival, although the test data are very limited. Recovery of the taggants appears to be a function of the specific conditions in which the explosion and taggant recovery take place, as well as the training of the field and laboratory investigators.

A large number of laboratory survival tests have been conducted to establish the postdetonation survivability of the 3M identification taggants. In many of these tests, the chamber used to recover the taggants was not ideal, resulting in low recovery rates. For example, when relatively small steel-walled chambers were used, the impacting taggants either broke up upon impact or flowed plastically due to the impact pressure pulse. When the explosive charges were detonated in large chambers, or on a large open pad, however, several hundred tags were recovered from a single one-half stick of the cap-sensitive explosives, including Atlas Power Primer, the most energetic of the standard commercial explosives. Similarly, the taggants should survive the detonation of black and smokeless powders, which have much lower energy than the more energetic explosives, under ideal conditions. The individual taggants are not expected to survive the detonation of high-energy explosives, such as the TNT used in boosters or military explosives; Aerospace Corp. calculations have shown that the taggant melamine would be raised above the taggant decomposition temperature in these explosives. Survival in these energetic explosives has been demonstrated when the taggants are pressed into large pellets (one-fourth inch), but no definitive recovery testing has been conducted.

When conditions are less than ideal, survival decreases. The number of surviving taggants decreases sharply as the size of the charge increases, although sufficient taggants have been recovered even from a 25-lb Power Primer charge to establish a definite identification. The number of taggants also decreases if the explosive is confined, for example, in a pipe bomb. Hundreds of taggants survive a black powder pipe bomb; tens of taggants have been recovered, under nonideal recovery conditions, from smokeless powder pipe bombs. Only one test seems to have been conducted with cap-sensitive high explosive in a pipe bomb; scores of taggants were recovered from a pipe bomb filled with 40 percent Extra, a low-energy explosive.

The recoverability of the taggants under real-world conditions is less well established. The vast majority of the tests of recovery have been demonstrations and training exercises, with little attempt at scientific controls, procedures, or documentation. Table 9 shows the results of 10 demonstrations using explosives tagged during the manufacturing process with encapsulated taggants at a 0.05 percent by weight tagging level. The number of taggants recovered is shown in each case. In some cases heroic recovery efforts were required. Statistical analyses by the Aerospace Corp. indicates that it is highly desirable to recover 20 taggants; that many were not recovered in each case. In some tests, particularly the last one, recovery was halted after the reported number was found. Table 10 shows the results of 14 similar tests, conducted without the assistance of the Aerospace Corp. and the BATF laboratory team. These tests were significantly less successful.

Due to the apparent inconsistency of the test results and the lack of documentation, OTA had a limited series of live recovery tests conducted. The purpose was twofold: to get a feel for the recovery process and its difficulties, and to generate a limited number of data points for which the testing, recovery, and analysis were well controlled and docu-

Table 10.—BATF Recovery Demonstrations

Place	Time	Target	Explosive	Test conditions	Taggant recovery
Birmingham, Ala.	February 1977	Car	1 1/2-lb Power Primer	Against engine; fire; firefighting	33 from soil sample in laboratory
		House	1 1/2-lb Coalite-8S	Table near front hall	Hundreds at scene
		House	1/2-lb 60% Extra in pipe	Outside house near wall	Several at scene
Donaldson, Pa.	March 1977	Borehole in coal mine	10 1/2-lb Coalite-8S	7 each 1 1/2-lb packages in separate boreholes	20 from coal in laboratory
Benson, Md.	June 1977	House	2-lb Coalite-8S	Exterior room	Dozens at scene
		Car	2-lb Coalite-8S	Passenger compartment	Few at scene
Fort McArthur, Calif.	November 1977	House	4 1/2-lb Powerdyne		Many at scene
Los Angeles, Calif.	August 1978	Open	1-lb Powerdyne	In suitcase	29 at scene
Otis AFB, Mass.	October 1978	Open	1-lb Tovex 220a	Three shots 1 lb each	Less than 50
Fort Belvoir, Va.	March 1979	Car	2-lb Coalite Z	Trunk	3 in field

a Unidentified shot had only 10 percent of expected taggants; this indicates that this explosive was from end of a batch.

SOURCE: Office of Technology Assessment.

Table 11.—Recovery Tests Participated in by Summit County (Ohio) Sheriff's Office

Date	Explosives	Target	Conditions	Recovery results
May 2, 1979	Total of 4 1/2 lb permissibles	Two cars, ground		2-hour field search (night) 10 men: 8 taggants in one car; no tags from other targets.
May 11, 1979	2-lb permissibles	Car	—	2-hour field search (night) by 2 men. No taggants.
May 17, 1979	3-lb permissibles; 1 black powder pipe bomb (untagged)	3 cars; pipe bomb in open	car fire	1-hour field search (daylight with Hackers). No taggants.
Oct 2, 1978	2-lb permissibles	Car		2-hour field search (night) by 2 men. No taggants.
May 18, 1979	1/2 pound ...	Car		1 1/2-hour field search (daylight with Hackers) 20 men. No taggants.
May 27, 1979	2-lb permissibles	Car		2-hour field search (night) by 2 men. No taggants.
Aug 9, 1979	2-lb water gel 1 3/4-lb gelatine dynamite 2-lb permissible	Car Car Car	Under driver seat Under driver seat Passenger seat	3-hour field search (dark), 8 men. Found 3 taggants from water gel. Laboratory analysis of 10-lb debris from each car. Found 6 more taggants from water gel.

SOURCE: Office of Technology Assessment.

mented. The results of the tests are summarized in table 11 and described in detail in appendix C. Sample photomicrographs of recovered taggants are shown in figure 3. Although these tests were extremely limited in scope and covered only one type of target (automobile), they provided a great deal of insight into the recovery process and suggest a reconciliation of the prior test results. However, a full-scale test program must be completed before a definitive assessment of taggant recovery is possible. With that caveat, the following tentative observations may be made:

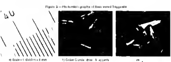
1. The recovery process does **not** appear to be a **field-readable** process under the tested conditions. No taggants were spotted and identified as such in any of the five tests under daylight or night conditions, without the use of a laboratory separation procedure. However, the recovery conditions were not ideal. Field recovery and identification of the taggants may be more likely on paved surfaces.
2. Under ideal conditions (no fire, subsequent firefighting activities, or adverse weather), sufficient debris can be gathered in a short time (less than 1 hour) by an untrained team to produce a positive taggant identification (more than 20 taggants) in the laboratory. Only a moderate (1 to 2 hour) laboratory effort is necessary by a highly trained laboratory team to isolate and identify the taggants. This probably holds for all classes of unconfined commercial explosives (excluding very high-energy explosives such as boosters or military explosives). The laboratory need not be elaborate and could well be transportable to the bombing site.
3. Under conditions of confinement (bomb placed between the engine block and the

Table 11.—OTA Recovery Test Results

Target	Placement	Dynamite	Test condition	Taggant recovery
Auto	Under driver seat	2-lb Collier C	5-gal gas in tank, no fire	26 taggants in 1 1/2-hour lab time
Auto	Under driver seat	2-lb Unigel	5-gal gas in tank, no fire	21 taggants [illegible] contaminant in ¾-hour lab time
Auto	Under driver seat	2-lb Power Primer	5-gal gas in tank, no fire	21 taggants in 1 1/2-hour lab time 12 of type A Dual taggants
Auto	Under driver seat	2-lb Collier C	5-gal gas siphoned in trunk, fire, firefighting	25 taggants in 3-hour lab time
Pickup	Between engine and firewall	2-lb Power Primer	Dry tank, no fire	28 taggants, plus one contaminant in 4 hours lab time. 5-hour reduction time preceded the search time due to confusion caused by equipment contamination.

SOURCE: Office of Technology Assessment.

Figure 3.—Photomicrographs of Recovered Taggants



a) Scale—1 division = 1 mm

b) Collier C under driver seat; 6 taggants on slide

[illegible]

[illegible]

e) Collier C under driver seat; 7 taggants on slide

[illegible]

Photo credit: [illegible]

firewall) sufficient taggants can still be recovered for a confirmed identification although somewhat more effort is probably necessary both in the field and in the laboratory. This tentative conclusion would hold for all cap-sensitive commercial explosives (excluding boosters and military explosives).

4. Taggants can be recovered from an automobile bombing with a low-power explosive even after a gasoline fire and subsequent firefighting efforts. Tests would be necessary to determine if taggants would survive a postdetonation fire in conjunction with a more energetic explosive. It should be noted that no fire occurred in

the three tests in which gasoline was placed in the gas tank. Fire had to be specifically induced (a gallon of gasoline was placed adjacent to the bomb) for the burn test.

5. The results of the automobile tests may well be generalizable to other test conditions (buildings, open areas), but testing would be required before that claim could be made.
6. No substantive recovery data are available for large charges, explosives in pipe bombs, tagged boosters, detonators or detonating cord, or charges consisting of an untagged blasting agent with a tagged booster and detonator. Taggants were reported recovered from a large bomb consisting of an untagged blasting agent and a tagged booster conducted in December 1979, but the test specifics have not yet been examined by OTA.

The technology for detection sensors has been demonstrated in the laboratory, but at least several years of development would be necessary before field models would be available. Three types of sensors are being considered for use with the microencapsulated vapor detection taggants. Each type is capable of sensing, under properly controlled conditions, in the parts-per-trillion regime envisioned for the system. The mass spectrometer sensor is a simplified version of a standard laboratory instrument. The spectrometer, however, must be calibrated regularly, requires skilled scientists to operate and maintain it, is large, and is quite expensive. The ion mobility spectrometer has been commercially available for approximately 5 years, with approximately 50 machines being used in laboratory analyses. It shares the laboratory instrument characteristics of the mass spectrometer. The continuous electron capture detector has been produced as a laboratory instrument, but in limited numbers. Laboratory and controlled environment testing with the three types of instruments has shown promising results. For example, a less sensitive mass spectrometer is currently operating in an online process mode at Libby Owens-Ford, maintained by regular maintenance personnel. Testing of the ion mobility spectrometer in an airport environment has indicated that the spectrometer can differentiate molecules of mass similar to the vapor taggants from the ambient environment. Similarly, laboratory testing of the continuous electron capture detector has indicated its ability to discriminate taggant-like molecules.

These limited tests, however, are a long way from demonstrating that the sensors can distinguish the specified vapor taggant species from other molecules, particularly those in the same mass range. The ion mobility spectrometer and mass spectrometer have an active separation mechanism to preclude interference with molecules that differ significantly in mass; the continuous electron capture spectrometer must rely on a far less reliable passive backup mechanism.

No estimates have been made of the time required to produce fielded units once a feasibility demonstration has been made (none of the three candidates has yet progressed that far). The only time estimate so far made is an estimate by the Aerospace Corp. that it would take 14 months from demonstration of feasibility to the completion of the prototype stage for the ion mobility spectrometer. This estimate is quite optimistic for an instrument that would be produced in large numbers by a small company. OTA feels it would be at least 3 years, and probably more like 5, before a taggant sensor could be fielded. The estimate is based on generalizing from other commercial and military instrument development experience.

The candidate detection taggant vapors appear promising, but more research is necessary. Several hundred candidate chemicals have been screened in a search for a vapor that exhibits the desired properties of scarcity in nature, long-term stability, chemical inertness, vapor pressure, penetration, and nonadherence to surfaces likely to be present in containers used to conceal bombs. The five candidate perfluorinated cycloalkanes appear promising on the basis of early tests. (No long-term stability data are available, however, nor are there data on the long-term stability of the diffusion rate through the encapsulating materi ed. Additional problems, such as ease of manufacture, specificity with respect to the detector and compatibility have not yet been addressed. Ease of manufacture is a double-edged problem — if manufacture is too difficult then costs will be high; if it is too easy then illegally manufactured material can be used as a countermeasure to the detection sensors. The most promising candidates are difficult to manufacture, require highly specialized equipment, and would be hard for bombers to make or acquire for use as countermeasures. Once the equipment is operational, unit costs should not be unreasonable. A problem which probably applies to all varieties of vapor taggants is that seals can be made that are taggant proof — although apparently common seals are insufficient.

COMPATIBILITY OF TAGGANTS WITH EXPLOSIVE MATERIALS

The compatibility of explosive materials with the specific identification and detection taggant materials is addressed here. Compatibility has two connotations: the first concerns the safety during manufacture, transportation, storage, and use of explosive material due to the addition of taggants; the second concerns changes in the performance of the explosive materials to which taggants have been added. Such compatibility must be demonstrated by specific tests. Generalization of the results to other hypothetical taggants is hazardous at best.

Safety tests conducted to date with the encapsulated 3M identification taggants have shown no incompatibilities with dynamites, gels, slurries, emulsions, or black powder, allowing a presumption that comprehensive testing would show that these taggants are compatible with these explosives. High concentrations of taggants do react with one kind of smokeless powder and one type of cast booster material at elevated temperatures and consequently incompatibility must be presumed pending further research. A large number of paired safety tests have been conducted comparing the sensitivity and stability of commercial explosives and gunpowders with and without identification taggants added. Safety tests included mechanical impact, thermal stability, thermal impact, friction, electrical properties, and chemical reactivity, although no single explosive has been subjected to all of the above tests. In no case did the addition of encapsulated taggants significantly increase the sensitivity of the explosive materials to the test conditions. No evidence of any decreased stability or other significant changes was found in any of the tests with dynamites, gels, slurries, or black powder.

The tests with tagged cast booster materials showed some indications of instability at elevated temperatures. A mixture of RDX and TNT (Composition B) showed evidence of reaction and probable decomposition at temperatures of 120° C when taggants were added to the booster mix; significantly less reaction occurred without taggants. Tests with Octol showed little reaction whether taggants were present or not. Pentolite showed little evidence of reaction with taggants in one test at 120° C; the gas evolution from untagged pentolite was too high for comparative testing on a second series.

Similarly, the stability of one type of Hercules smokeless powder has been shown to be significantly decreased by the addition of the 3M identification taggants at elevated temperatures and taggant concentrations. (Although Hercules tested only Herco* powder, Hercules believes that their other brands of powder designed for the reloading market are so similar to Herco* that similar test results could be expected.) Tests were conducted at temperatures ranging from 65° to 120° C and at taggant concentrations of 50 percent. Tests at the Lawrence Livermore Laboratories appear to indicate that the incompatibility is between some element of the powder and the basic melamine/alkyd material of the taggants, rather than with the magnetic or a pigment.

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* A registered trademark of Hercules Inc.

Both the smokeless powder and booster material tests took place at high temperatures and in most of the tests at high taggant concentrations. The temperature used for the smokeless powder test was higher than would be expected in actual manufacture, storage, or use; the temperature used for the cast booster is sometimes reached in manufacturing processes. In each test, a taggant concentration of 50 percent was used rather than the 0.05 percent tagging concentration suggested for routine use. The tests, nevertheless, indicate that the stability of the materials has decreased due to the addition of taggants, and that a reaction is taking place between elements of the taggant and elements of the explosive material. Standard qualification test procedures require that such evidence be considered a sign of an existing incompatibility between the materials. Carefully controlled testing and extensive analysis must be completed before it can be determined if the observed evidence of incompatibility does, in fact, indicate a potential safety problem during the manufacture, storage, transportation, and use of the tested materials. Unless demonstrated otherwise, it must be assumed that it is unsafe to add the taggants to that smokeless powder or to the booster material. Until the elements of the incompatibility have been identified, a question remains as to the safety of adding the taggants to similar smokeless powder and booster materials, although tests with other smokeless powders and boosters have shown no evidence of incompatibility.

The tests so far conducted are only a small fraction of the total number of tests that must be performed before it can conclusively be determined whether taggants are compatible with commercial explosives and gun powders.

Even if the current question of the stability of smokeless powder and boosters is resolved, **it is not possible to generalize from the results of the limited test program so far completed and conclude that the testing has demonstrated that taggants can be safely added to explosives.** Thousands of people come into contact with explosives every day during the manufacture, storage, transportation, and use of explosives. Accidents involving explosives can have extremely severe consequences to these thousands of people; therefore, safety must be demonstrated. A carefully administered qualification program of analyses, safety testing, manufacturing procedures control, and experience is necessary before a new explosive, or an explosive with a significant change in composition, can be considered safe. In addition, each type of explosive product requires individual evaluation and testing. The type of qualification program considered necessary before safety can be demonstrated is shown in table 12 and discussed in detail in chapter IV. A particularly important aspect of that qualification testing is the effect of long-term storage.

Table 12.—Elements of a Suggested Compatibility Qualification Program

- analyses with each manufacturer
- analysis to define the new explosive or ingredient
- laboratory testing
  - impact, friction, thermal, chemical composition
  - electrical, aging, chemical interactions, performance
- pilot production
  committee and management review
- early production and review
  special tests
- experience

SOURCE: Office of Technology Assessment.

While the qualification program outlined in table 12 must be performed before taggants can be safely added to explosive materials, **the apparent incompatibility with the Herco® smokeless powder must be resolved before it makes sense for the taggant compatibility qualification program to proceed. Resolution** of this problem is pertinent to the entire identification taggant program, not simply for smokeless powders or for Herco®. As discussed in detail in chapter VI, smokeless powders are used in a significant number of criminal bombings nationwide and account for a significant fraction of bombing casualties. If smokeless powders are not controlled, then more bombers may well switch to their use, resulting in an even greater smokeless powder bombing problem. The resolution could take any of several forms, including

Reformulation of the 3M taggant — this could require starting essentially from scratch in the taggant testing program as the reformulated taggant would undoubtedly exhibit different compatibility as well as survivability properties.

Reformulation of the particular reactive smokeless powder—this may or may not be easily accomplished once the element or elements that react with the taggant are isolated. This option would be viable only if no other smokeless powders were found to show incompatibilities.

- *Exclusion of the reacting smokeless powder from the taggant program*—the economic effects on competition again need to be carefully considered as would alternate control mechanisms.
- *Exclusion of smokeless powders from the identification taggant program* — such an exclusion would rely on the fact that smokeless powders would be less attractive than cap-sensitive high explosives and that the detonators would be tagged. OTA believes that this last approach may not be viable—too many people are currently killed or injured by devices using smokeless powders and the numbers would almost certainly increase if this approach were adopted. Alternate control mechanisms for smokeless powders could also be adopted.
- Development of a different type of taggant for use with Herco® or with all smokeless powders, while retaining the existing taggant for high explosives. This would somewhat complicate field investigation of bombings.
- Demonstration that the observed stability problem does not constitute a safety hazard. The observed decreased stability occurred at elevated temperatures and taggant concentrations 1,000 times greater than "normal." As the decomposition rate is both temperature and concentration sensitive, it may be that no safety hazard exists under realistic conditions. If it could be positively demonstrated that the decomposition rate was within the normally accepted range for temperature regimes and concentrations which reflect worst case actual use conditions, then it *may* be possible to add taggants to the smokeless powder, particularly if no further incompatibilities surface. Demonstration of safety would have to be quite convincing, however, to overcome the currently perceived incompatibility.

Similarly, the apparent incompatibility with one cast booster material should be resolved before the taggant compatibility qualification program should proceed. Booster material is rarely used as a bomb filler but it is used to initiate blasting agents. The current BATF plan would be to not directly tag blasting agents, but to tag the booster and detonators used to initiate the blasting agent. Exclusion of boosters from the taggant program may well require an alternate control mechanism for blasting agents. Given the extremely large quantity of blasting agents produced (3.4 billion lb annually), any other control mechanism may have serious cost consequences.

The limited number of tests conducted, the conditions under which some of the tests were conducted, and the preliminary manner in which the tests have been reported make it difficult to definitely assess the extent of the potential compatibility problem. If definitive test results do show an increased decomposition rate of cast RDX/TNT explosive materials, the incompatibility will have to be resolved before these booster materials can be tagged. Most of the mechanisms for resolution of the smokeless powder incompatibility are applicable to booster materials, with the same consequences and caveats.

While the testing program conducted to date gives an indication that the identification taggants may well be compatible with most commercial explosives and gunpowders, **little data are available as to the potential compatibility of detection taggants with explosive materials.** Compatibility testing with gunpowders and cap-sensitive high explosives has recently been initiated under contract to the Aerospace Corp. however, no compatibility testing has as yet been reported. As indicated above, each change to an explosive composition must be evaluated separately. Successful completion of the preliminary detection compatibility program would indicate the need for a full qualification program. As some compounding of sensitivity may occur with both types of taggants present, the full qualification testing program should address that issue.

Compatibility testing includes performance testing as well as the safety testing discussed above. **In most cases, the performance of explosive materials is unlikely to be significantly affected by the addition of small amounts of taggant materials. Performance proof testing must be completed, however, before a definitive statement could be made.** The energy density and rate of energy release are the two most important performance attributes of commercial explosives. Energy density is a fundamental chemical property of the explosive formulation. The rate of energy release is a function of the materials involved and the physical proximity of the fuel and oxidizer components. The presence of taggants, in the few hundredths-of-a-percent by weight being considered, is unlikely to directly affect either of these performance characteristics. Similarly, the presence of taggants in the suggested concentration is unlikely to affect the ballistic properties of gunpowders. The few tests conducted so far, including tests of the basic properties of explosive materials, such as detonation velocity, cap sensitivity, chamber pressure, and projectile velocity, support that conclusion.

Physical segregation of the taggants is one mechanism which could affect performance. If the gunpowder grains segregate from the taggant, then it is statistically possible that a clump of taggants could cause uneven burning, prevent ignition, or result in a hazardous hangfire condition. Similarly, in some specialty explosive products, such as shaped charges used for oil well perforations, migration of the taggants to the explosive-metal interface could cause poor jet formation. Testing with gunpowder has shown that migration apparently does occur, at least under vibration conditions consistent with truck transportation. In tests with gunpowders that differ in both size and density from the taggants, the taggants and powder fines tend to separate from the larger powder grains. Tests with smokeless powder matched in size with the taggants, but different in density, were inconclusive. Testing is required to determine both the extent of segregation which could be expected if tagged gunpowders went through extreme but plausible conditions of transportation and storage, and also the statistical probability that segregation to this degree would adversely affect ballistic performance or in-gun safety.

The Winchester-Western Division of the Olin Corp. recently conducted a series of tests to evaluate the effects of segregation and high taggant concentration on the ignition properties of smokeless powder. Significantly reduced ballistic performance was noted on one round fired at –30°C with four times the suggested taggant concentration. The other rounds fired in this test series showed acceptable performance (velocity, chamber pressure, and ignition time).

Olin Winchester conducted additional tests using 100-percent segregation of taggants from powder grains, a condition so extreme that no conclusions can be drawn (see ch. IV).

OTA believes that although testing is indeed required to establish the ballistic effects, if any, of adding taggants to smokeless powder, it is necessary first to establish (by testing and by statistical analysis) the extent to which variation in taggant concentrations and segregation of taggants in normal conditions of transportation and use could be expected.

Taggant clumping (10 to 15 taggants) sometimes occurs when the taggants are added to explosive materials. It is unlikely that the clumping would affect performance or safety, but that type of anomalous behavior should be investigated, particularly as the physical chemistry of some of the explosive products, particularly the gels and slurries, is so poorly understood.

As for the possible performance degradations in shaped charges due to taggants, OTA estimates based on tests conducted by the U.S. Army Ballistics Research Laboratory indicate that a clump as large as 0.02 inch would not affect performance, even for precision-shaped charges, unless the clump contained a large hollow center. Clumps as large as 0.1 inch could cause some degradation to occur. It is difficult to envision a mechanism which would allow that large a clump to accumulate, or that would represent all of the taggants in approximately one half [illegible] of explosive.

COST OF A TAGGANT PROGRAM

Estimates can be made of the total cost of a taggant program, the cost impact on manufacturers and users of explosives, the effects of a legislated monopoly, and the possibility of added liability of manufacturers due to the inclusion of taggants in explosives. In the above safety and efficacy discussion, the status of the current identification and detection taggant systems was evaluated. In the following cost section, an assumption is made that the taggants work and are safe, and cost estimates are generated parametrically as a function of the implementation plan. It is specifically assumed that the resolution of the smokeless powder and booster material incompatibility questions and any subsequent questions which may arise do not have significant cost impacts. In the case of the smokeless powder and booster materials, this assumption is probably justified, as the cost of the taggant materials represents only a small fraction of the total cost added by a taggant program.

The primary finding of the cost analysis is that **the cost of a taggant program can vary by almost an order of magnitude depending on the implementation plan. A baseline program is identified that would increase the cost of explosives and gunpowders to the ultimate user by approximately 10 percent.** The primary variables affecting the total program costs are the class of explosive materials to be tagged, the uniquely tagged batch size, and the number of locations at which the detection sensors would be deployed. Cost estimates for total program cost, added cost per pound of explosive or gunpowder, and public overhead costs are shown in table 13 for three implementation levels. The cost estimates include the costs for both identification and detection taggant programs. The total program cost for separate implementation of identification and detection taggant programs is included in the discussion of each case. The low, baseline, and high cost estimates do not correspond to different estimates of the same program; rather they refer to different tagging levels, different explosives tagged, and different numbers of sensors. Chapter V contains a detailed discussion of the cost estimates and a discussion of the sensitivity of the costs to the accuracy of the cost element estimates. To compare the program costs for a constant number of detection taggant sensor locations, it is only necessary to adjust the high- and low-program cost figure by $4,370 for each sensor deployed.

Table 13.—Cost of a Taggant Program as a Function of Implementation Plan

Cost parameter	Program level		
	Low	Baseline	High
Added cost per pound to cap-sensitive explosives	$.03	0.05	0.60
Added cost per pound to gunpowders	$.50	[illegible]	1.74
Public overhead cost, millions of dollars per year	$5.3	$8.0	$24.5
Total program costs, millions of dollars per year	$31.0	$45	$268

SOURCE: Office of Technology Assessment

1. The low-level program would use a unique identification taggant for each manufacturer, type of product, and year of manufacture. A total of 800 detection sensors would be deployed, one for passengers and one for baggage at each airport location currently deploying magnetometers and hand baggage X-ray units. Cap-sensitive high explosives, detonators, boosters, detonating cord, and smokeless and black powders would be tagged with both identification and detection taggants. Blasting agents would not be directly tagged. The

cost of separate low-level identification and detection taggant programs would be approximately $15 million and $22 million, respectively.

2. The baseline program would tag the same materials as the low-level program, but would use a unique identification taggant for each shift of each product—analogous to the current date-shift code marking on the exterior of explosives. Traceability to the list of last legal purchasers would be maintained, as the taggants would contain all the information needed for a BATF trace (date, shift, product, and size). Approximately 2,500 detection taggant sensors would be deployed at airports and major controlled-access facilities such as powerplants, refineries, and Government buildings. Major police bomb squads would operate portable units.

   This baseline program differs from the program proposed by the BATF/Aerospace Corp. team in only two respects. The most important is that a full shift of the same product (a different cartridge size would be treated as a different product) would be tagged with the same taggant, rather than an arbitrary 10,000 to 20,000 lb. The practical utility result is that a potentially longer list of last purchasers would be produced by a trace, at least for those lines that make more than 10,000 to 20,000 lb of a product in a single shift. The second difference concerns rework. It has been assumed that a special taggant will be added to material with more than 10 percent cross-contamination; such a taggant would indicate that the material used was a composite and that taggant codes other than the specific composite code should be ignored.

   The cost of separate baseline identification and detection taggant programs would be approximately $25 million for each.

3. The high-level program would uniquely tag each 10,000-lb batch of explosive and each 2,000 lb batch of gunpowder. All explosive materials, including blasting agents, would be directly tagged. Ammonium nitrate fabricated for use in blasting agents would be tagged, but not fertilizer-grade ammonium nitrate. Approximately 5,000 detection taggant sensors would be deployed at every major transportation facility, controlled-access facility, Government facility, and other potential high-value targets such as company computer locations. Portable units would be routinely available to police bomb squads. The taggant level and types of explosives to be tagged in the high-level program correspond to a strict interpretation of S. 333 as propounded by the Institute of Makers of Explosives (IME). The cost of separate high-level identification and detection taggant programs would be approximately $214 million and $65 million, respectively.

The identification taggant cost figures used in all three levels of the analysis are based on price estimates furnished by 3M for specific implementation guidelines. 3M furnished management-approved cost estimates for unencapsulated taggants for three different quantities of explosives to be tagged, assuming a firm order for 2 years (costs would remain the same for a 5-year contract). These cost estimates represent the firmest figures possible short of an actual contract. Assuming linear interpolation between data points furnished, the unencapsulated taggants would cost between $85 and $114/lb for the amount of taggants necessary for the baseline level case (41.5 million lb of explosive equivalent). The first figure represents a cost goal and the second a worst case estimate. 3M technical people also furnished an estimate of encapsulating cost, but were unable to estimate the cost of the opaque encapsulation assumed by OTA as the baseline product. Based on the above data, OTA estimated that it would cost approximately $55/lb for opaque encapsulated taggants; as the baseline tagging level is 0.05 percent by weight of encapsulated taggants, and the encapsulating material weighs the same as the unencapsulated taggants, this corresponds to 2.75 cents/lb of explosives for the identification tagging material ($83 for 1 lb of nonencapsulated taggants plus $17 for 1 lb of encapsulating material plus the process equals $110 for 2 lb of encapsulated taggants, or $55/1 lb). OTA estimated the same cost for taggants at the other two implementation levels. Chapter V includes an analysis of how changes in the cost and/or concentration of the taggants themselves would affect the cost of the program.

All other cost figures are estimates based on specific inputs submitted to OTA by manufacturers, distributors, and end users. Detailed treatment of the cost elements is contained in chapter V.

The cost impact to end users of explosives can be considerable. Implementation plans that do not take into account the impact on manufacturers and users of explosives could drive a number of manufacturers and users out of the market, could make some classes of finished products like copper uncompetitive in the world market, and could force entire segments of industry to radically change operating procedures, such as shifting underground coal mining from explosive mining to mining machines. Detailed discussions and analysis, however, indicate that **it is quite unlikely that a taggant program similar to the "baseline" would eliminate any current uses of explosive materials, although marginal companies and product lines might be eliminated. As indicated above, the baseline program differs from the BATF-proposed implementation only in that batch size takes into account** the normal production processes and quantities of the explosives and gunpowder manufacturers. This finding is based on detailed discussions with a limited number of users and manufacturers about current costs and the possible impact of cost increases.

Some examples are illustrative. Increasing the cost of cap-sensitive high explosives the 12 percent projected would increase the cost of extracting coal in a particular modern underground mine by only 0.1 percent. Such a small increase would not be significant to this intensive user of cap-sensitive explosives and would be quite unlikely to cause a shift to mechanical mining machines or render a particular mining operation uneconomic. Similarly, that type of increase in the cost of cap-sensitive explosives, boosters, detonators, and detonating cord in a large, open pit copper mine would increase the cost of producing copper only 0.03 percent. As blasting agents are currently used whenever possible in that mine (cap-sensitive explosives are used only for secondary breakage), no shift in explosive products used would take place. The cost of a recent explosive-intensive dam construction project would increase 1 percent under the baseline program, a larger percentage, but not enough to be significant or force alternatives. A price differential of approximately five-to-one currently exists in favor of blasting agents over cap-sensitive high explosives, which has caused most users of explosive materials to consider blasting agents, and shift where feasible; an increase in that differential to six-to-one is unlikely to significantly change the current status.

As a final example, consider the cost impact on handloaders. Handloaders load their own ammunition for two reasons—economy and the hobby aspect. A less-than-10-percent cost increase in expendable material is unlikely to affect a hobby in which hundreds of dollars in costs have already been incurred (hand loading equipment and guns). As powder is only one of several materials on which a handloader saves costs (cartridge cases, projectiles, wadding) and additional cost savings are realized from labor and by eliminating the excise tax on purchased ammunition, an 8-percent increase in powder cost would translate into an even smaller increase in total reloading costs. It is possible, however, that manufacturers would shrink the range of available product lines in order to minimize the startup costs of tagging. A smaller choice of products would be an additional cost to the handloader.

The identification taggants currently proposed to be used are manufactured only by 3M and are a proprietary product manufactured by a proprietary process. In addition, a significant public overhead cost would have been incurred before the compatibility of explosive materials with the taggants could have been demonstrated. Mandating the addition of identification taggants to explosive materials would therefore ensure a monopoly of the Government-mandated market for 3M, at least for a period of several years. Under such circumstances, **development of a mechanism to regulate the virtual monopoly of the identification taggant market which 3M would enjoy is highly desirable.**

A number of mechanisms are available to regulate the price of taggants, including:

1. a price level set by Congress in the enabling legislation;
2. regulation as a public utility;
3. licensing by 3M of competitors;
4. a multiyear fixed-price contract; and
5. a free-market price, regulated only by the possibility of competition or sanctions if prices get too high.

The free-market mechanism may be unacceptable to manufacturers of explosives and gunpowders given the long time needed to either develop and qualify an alternative taggant or enact sanction legislation. Legislation of a price or use of a regulation mechanism similar to that used for public utilities would be an awkward, time-consuming process for a product whose total annual value would be on the order of $10 million.

Licensing is not only disagreeable to 3M, but it is probably not cost-effective. The cost of the taggant material includes a component for amortization of the taggant production facility, as a new facility must be built and the primary market for identification taggants would likely be the mandated explosives market. The process which 3M plans to implement is capital intensive. Licensing of other manufacturers would therefore require the construction of facilities for the licensee, in addition to a new 3M facility, resulting in a substantially higher total cost.

A long-term contract is a potentially attractive mechanism. In fact, the 3M cost estimates are conditional on firm orders for a 2-year period, although 3M is willing to consider contracting periods of up to 5 years. The details of the regulating mechanism have not been addressed by this study. If a multiyear contract is an acceptable mechanism, there may be some advantage to a single contracting agency (presumably within the Government) rather than separate contracts with each manufacturer of explosives and gunpowders. In addition to saving the cost of multiple contracting, the single contract concept would limit the amount of information on numbers of product lines and production quantities of explosives available to 3M, a matter of some sensitivity to the explosive manufacturers.

A final cost-related issue merits attention. **The legislation of a taggant program might change the extent to which manufacturers are held liable for accidental explosions.** In the event that an accidental explosion takes place, those injured may attempt to hold the manufacturer of the explosives, the seller of the explosives, or the manufacturer of the taggants liable. The addition of taggants to explosives could change the existing situation in several possible ways:

- The use of taggants would make it easier to identify undetonated explosives from the same batch as those involved in the accident, thus facilitating proof or disproof of allegations that the explosive, the taggant, or both were incorrectly manufactured.
- Evidence that incorrectly manufactured taggants had been involved in an accident would probably subject the taggant manufacturer to liability, regardless of any disclaimers made at the time of sale.
- Evidence that taggants had been incorrectly added to explosives (e.g., an excessive concentration) might expose the explosives manufacturer to liability if evidence could be presented that such a high concentration posed a danger.
- There should be no cases in which the evidence shows that taggants were manufactured and used correctly, due to the extensive qualification program required to demonstrate taggant safety. In any event, the fact that Federal law required the use of taggants would be a defense.

- If, however, taggants actually create a hazard (and there is no evidence that they do so), the manufacturers of explosives might be exposed to liability based on an (incorrect) assumption that the manufacturing process was somehow at fault.

Furthermore, Congress could include in the legislation mandating a taggant program provisions deciding who should bear the costs of accidents. For example, Congress could shift the cost to the Government by allowing suits against the Government for accident losses allegedly due to taggants. Alternatively, by legislating a presumption that taggants are safe or simply by granting immunity to manufacturers, Congress could shift the cost of any taggant-caused accidents to explosives users. A third possibility would be to legislate in a way that would make taggant and/or explosives manufacturers liable for accidents caused by taggants despite legislative coercion to use them. A final option would be to divide the costs of accidents by legislative limits on the dollar amount of claims arising from accidents allegedly caused by taggants. The issue of liability is treated in detail in appendix D.

UTILITY OF TAGGANTS

Before the utility of identification and detection taggants to law enforcement, security, and other regulatory agencies can be assessed, it is first necessary to examine the bomber threat in some detail. The utility against each segment of the bomber population can then be assessed, together with the possible responses of the criminal bombers, and be compared to the utility of other control methods. Identification taggants may also have utility for purposes other than tracing of criminal bombers.

The bomber population of the United States is extremely heterogeneous, with varying motives, resources, skills, and ability to adapt to a changing control environment. For ease of discussion, bombers are divided into four categories which differ from each other in most characteristics. These categories include terrorists, common criminals, the mentally disturbed, and vandals and experimenters. The characteristics of the various types of bombers are summarized in table 14 and briefly described below.

Terrorists

The terrorist groups active in the United States vary widely in ability, resources, training, and objectives. They share the common characteristics, however, of high motivation, action as a part of a group, and a continuing involvement in catastrophic illegal activities against society. These characteristics make the terrorist particularly dangerous to society and a particularly appropriate target for anti-bombing controls. Terrorists can be roughly divided into political, reactionary, and separatist groups. Political groups are primarily interested in attracting attention to, and sympathy with, their cause. For that reason they engage in spectacular events, such as bombings, but generally attempt to avoid or limit injury and death resulting from their bombings. Political terrorists often have considerable resources available to them, due to the significant number of people who support their aims, if not necessarily their means. The leadership of most of these groups are of above-average intelligence and have either had specialized training or have studied extensively in terrorist activities. They are thus able to adapt to a changing environment, although the range of responses available to them may be limited by their political aims. Such political groups have been relatively inactive in the United States in recent years.

Separatist groups, such as FALN (a Puerto Rican terrorist group), generally hope to gain their aims by generating a reaction to their activities, rather than a sympathy for their aims. They are therefore generally less concerned with public revulsion to bombings that cause

Table 14.—Attributes of Criminal Bomber Groups

Perpetrator	Experience and training	Resources	Motivation	Individual or group	Reaction capability	Frequency
Criminal						
Unsophisticated	L	L	M		M	Multi
Sophisticated	H	M	H		H	Multi
Terrorist						
Political	M-H	M-H	M-H	G	M-H	Multi
Separatist	M-H	M	H	G	H	Multi
Reactionary	L	L	H	G	L-M	Multi
Mentally disturbed						
Dissociated	L	L	L-M		L	Single
Vengeful	L	L	M-H		L-M	Single
Pathological	L-M	L	H		L-M	Varies
Other						
Vandalism	L	L	L-M		L	Single
Experimenter	M	L	L-M		L-M	Single

[illegible] Office of Technology Assessment

substantial injury and deaths. Separatist groups have been credited with more than 25 percent of catastrophic bombings—those resulting in major property damage, injuries, and deaths. The resources of domestic separatists vary from group to group, but are generally less than for comparable groups of political terrorists.

Reactionary groups such as the Ku Klux Klan and the American Nazi Party share some of the characteristics of the political terrorists, but generally do not possess the same levels of training, motivation, and resources, and are not as capable of reacting effectively to a changing control environment. They also differ in that their bombings are usually directly targeted at the individual or group they intend to influence, rather than simply at a spectacular target.

Terrorists have been responsible for approximately 12 percent of those bombing incidents in the past 5 years to which law enforcement agencies assigned a motive.

Common Criminals

Criminals range from the petty operator who utilizes a bomb for extortion to the professional bombers of organized crime. The petty operator is generally poorly trained, is not very motivated, has limited resources, and cannot readily adapt to a changing enforcement environment. The only major characteristic he shares with the professional bomber is that his targets are generally individuals or small commercial establishments unlikely to be protected by a detection taggant sensor. The professional bomber is highly trained and motivated and generally has considerable resources available to him, either directly or through his "employer." Criminals share with terrorists the characteristic of engaging in repeated bombings, but differ in that the professional criminal bomber usually works alone rather than as part of a group. Criminals as a group are responsible for approximately 6 percent of bombing incidents. Most incidents are limited to specific targets and do not generally cause substantial injury or death to innocent bystanders.

Mentally Disturbed

The mentally disturbed bomber differs from terrorists and criminals in that he generally does not engage in multiple bombings, although exceptions such as the Los Angeles "Alphabet Bomber" certainly exist. He generally is poorly trained, has limited resources, and acts alone. He is often highly motivated, but perhaps only for short periods of time, in direct response to some stimulus. He is extremely limited in his ability to respond to changing control situations, either through lack of care of consequences or belief in his invincibility. As his motives are hard to identify, it is difficult to predict his targets.

Vandals and Experimenters

Vandals and experimenters share the characteristics of poor training, limited motivation, and limited resources. They generally work alone or in small groups, and do not generally intend to harm people or cause extensive damage. Their targets are often of little value, like mailboxes or outhouses, but some acts of vandalism can cause extensive damage to buildings such as schools. While accounting for over 40 percent of the reported bombing incidents, they are responsible for little damage and few casualties.

Given the diversity of the criminal bomber population, the range of targets involved in bombings, and the choice of explosives available to the bombers, it is difficult to assess the utility of taggants to law enforcement agencies. The assessment is made particularly difficult by the lack of experience with taggants, although the McFillen case (recently tried in Baltimore) provides one example where identification taggants were an extremely important piece of evidence linking a suspected perpetrator to the crime. Inferences can also be made from experience with the date shift code and with the X-ray machines and magnetometers used at airports to prevent hijackings. A useful construct for viewing the findings is shown in table 15, the discussion of which follows.

Both identification and detection taggants would have limited utility in combating bombings of low-value targets. Due to limitations on law enforcement time and resources, minor bombings, such as a vandalism bombing of a mailbox, do not warrant as thorough an investigation as bombings involving casualties or significant property damage. In New York, for example, such cases are generally handled at the individual precinct level without the use of the trained bomb squad, bombing investigators, and forensic chemists. As evidenced by the results of the recovery demonstrations, a visual search of the area by untrained law enforcement personnel is unlikely to turn up identification taggants. Similarly, detection taggant sensors are unlikely to be present before the detonation. The lack of utility in these cases, however, does not greatly diminish the overall utility of a taggant program, as the intent of the program is not to prevent this type of bombing, but to help prevent significant bombings and to help in the arrest and conviction of the perpetrators of such bombings.

Table 15. Taggant Utility Summary

Specific bombing conditions	Identification taggants	Detection taggants
Low-value targets	Limited utility	Limited utility
High-value targets, no bomber countermeasures	High utility	Extremely high utility
High value targets, bomber countermeasures	Countermeasures costly due to increased risk	Countermeasures require technical knowledge, planning

SOURCE: Office of Technology Assessment

Identification and detection taggants would provide a quantum increase in utility in combating bombings of high value targets, assuming the absence of effective bomber responses.

The current procedure for the apprehension and conviction of criminal bombers consists of three phases:

1. the postdetonation search of the area for physical evidence,
2. the investigation, based on the results of the analysis of the physical evidence, and
3. intelligence gathering on, and surveillance of, suspected perpetrators or expected targets.

The search for evidence phase includes a detailed analysis to try and determine the type of explosive used (successful approximately 50 percent of the time) and examination of whatever parts of the bomb, such as elements of the timing device, may have survived the detonation. This evidence, together with any evidence of the presence of the perpetrator (such as hair or fingerprints), serves as the starting point for the investigative phase.

The investigative phase consists primarily of trying to generate some type of lead to the perpetrator from the physical evidence gathered, as well as checking leads provided by informants or witnesses and attempts to correlate the characteristics of the bombing with similar instances. A great deal of effort may be expended, for instance, in investigating the sources of a common clock used as the timing mechanism.

The addition of identification taggants to explosives would aid the investigatory efforts of law enforcement personnel in a number of ways, provided that tagged explosives are used, the taggants survive the detonation, and the taggants are recovered from the explosive debris. The taggants provide a good starting point for an investigation as they directly indicate the type of explosive used, manufacturer, time of manufacture, and provide a list of the last legal purchasers. This information may lead directly to a bomber who purchased the explosives legally. In some cases, the bomber would not otherwise be identified with the bombing. In others, as was the case with the McFillen incident in Baltimore, the taggants add a strong link in a chain of evidence which may help to obtain a conviction. Taggants may provide intelligence information, such as linking a series of bombings, or linking a suspect to a theft of explosives by establishing that one of the legal purchasers reported a theft at the time the suspect was in the city in which the theft occurred. Finally, bombers may be deterred from committing bombings by the knowledge that the chances of their being apprehended are increased by a taggant program.

In order for the taggant information to be useful, however, the bombing must be of sufficient importance (in terms of property damage, notoriety generated, or casualties produced) to warrant a thorough investigation. In such cases, identification taggants will provide much more information—and more reliable information—than present methods, and this information will require much less effort by the investigating team.

The value of the list of legal purchasers will depend somewhat on the length of the list. A trace which indicates that the full taggant batch of explosives was sold directly to a mine by the explosives manufacturer obviously provides more useful lead than a trace which shows a large number of purchasers of a lot of smokeless powder. Even for the smokeless powder case, the list of names would probably not be excessively long. The types of bombings likely to warrant a detailed investigation are unlikely to be caused by 1 or 2 lb of gunpowder, eliminating most purchasers from the list or providing multiple traces of the multiple lots blended to make up the filler.

The utility of detection taggants in protecting high-value targets is obvious. The current procedures for protection of potential high-value targets vary with the type of the facility and the time since the last perceived threat. Airports are protected by requiring all carry-on luggage to go through inspection (usually X-ray) and all passengers to walk through a magnetometer. Search of checked baggage is not routinely required, although spot checks, sometimes with trained dogs, do occur, particularly when the perceived threat is high. Many Government buildings and other controlled access facilities require a package or briefcase check as well as personnel identification to gain entry. The airport instruments are operated and inspection checks conducted primarily by personnel who are poorly trained, poorly paid, and subject to the problems of maintaining alertness over long periods while performing a dull job. The magnetometers are useful solely to detect metal, and information from the X-ray machines must be interpreted by the attendant. The use of a self-calibrating sensor which would reliably give an alarm at the presence of explosives in hand baggage, checked baggage, or on a person would offer an enormous increase in utility over current methods.

Many of the criminal bombers who would be likely to attack a high-value target would be deterred by the knowledge that the target was protected by a sensor that would detect the explosives in their bombs (assuming no effective countermeasures by the bomber). The deterrence might work to redirect the bomber against another target, to cause a less vulnerable part of a target to be attacked, or (perhaps infrequently) to deter the attack altogether. Those who were not deterred would have their bombs interrupted, protecting their target and providing security personnel with additional clues to the perpetrator.

Detection taggants would only provide utility to those targets that were protected by a detection taggant sensor. Portable detection taggant sensors would also be quite valuable in locating a bomb whose approximate location was known and in determining if a suspected package contained explosives.

In summary, identification taggants would provide a genuine increase in utility for those bombings significant enough to warrant a thorough investigation, while detection taggants would provide that increased utility in protecting those potential targets sufficiently important to warrant a detection taggant sensor.

The above discussion assumes that the criminal bombers do not respond to the introduction of a taggant program. However, **countermeasures exist which would enable bombers to evade the effects of a tagging program. The available countermeasures require varying degrees of specialized knowledge, and some of them involve significant risks. Because most bombers would probably not avail themselves of the possible countermeasures, a taggant program would probably retain substantial law enforcement utility.**

Bombers seeking to respond to a taggant program by using countermeasures can use any of several approaches:

- removal of the taggants,
- fabrication of homemade explosives,
- use of incendiary bombs,
- theft of explosives,
- black market purchase of explosives,
- use of explosives manufactured before the taggant program commenced,
- use of blasting agents,
- sealing of detection taggants,
- "spoofing" of taggant sensors, or
- resorting to another unlawful activity such as assassination or kidnapping.

The baseline 3M identification taggants contain both a magnetic layer and a fluorescent layer to aid in recovery after a detonation. The taggants could therefore be removed from powdery explosives by using a magnet. The process would be both easy and safe, and would require less than an hour for a typical bomb. In order to hinder this countermeasure, taggants have been manufactured without a magnetic layer. If a powdery explosive were tagged with a mixture of magnetic and nonmagnetic taggants, then the use of a magnet would enable a criminal to remove only a portion of the taggants; the remainder would be present after an explosion, although they would be somewhat more difficult to recover than the baseline taggant. If the criminal were deterred from attempting magnetic removal by the knowledge that about half the taggants were nonmagnetic, then postdetonation recovery would be only marginally more difficult than the baseline case.

Another possible technique for removing taggants from an explosive is to use a black light to identify the taggants by their fluorescence, and then remove them with a tweezer. This process is safe, but more difficult than magnetic separation, and would probably require many hours of painstaking effort for a typical bomb. Unlike magnetic separation, it could be used to remove taggants from explosives that are lumpy rather than powdery. It has been proposed that the encapsulation of the taggants be made opaque and matched to the color of the explosive in order to render such removal impossible. Since the encapsulant would be melted by the heat of a detonation, postdetonation recovery would not be affected. Although it should not be difficult to develop an opaque encapsulant, this has not yet been done. Opaque encapsulation would make quality control, both of manufacturing taggants and mixing them with explosives, more difficult, and its cost impact has not been evaluated.

In order to remove a nonmagnetic taggant with an opaque encapsulant from an explosive, the explosive would be carefully dissolved, the taggants and other solid material removed by filtering, and the explosive reconstituted. This complex operation would require specialized knowledge, be roughly equivalent in danger and difficulty to fabrication of explosives from raw materials, and would result in less reliable (less likely to detonate) explosives.

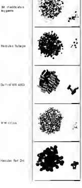
Taggant removal from some gunpowders could be significantly easier than from explosives, as some gunpowder grains are considerably larger than the identification taggants, as shown in figure 4. Separation from these powders may therefore be accomplished simply by screening, even if the taggants are nonmagnetic. Tests with several Du Pont IMR powders have shown that it would be difficult to separate the taggants from the chips and fines contained in the gunpowder package, but all small particles could easily be separated from the intact grains by screening. It has been proposed to alleviate the problem by agglomerating the taggants into clumps whose size roughly matches the specific powder grain size. The cost impact of such a solution was not addressed during this study.

Removal of the detection taggants would not be feasible.

Fabrication of explosives may be accomplished by a variety of means, but a considerable degree of expertise is required to avoid the risk of premature detonations, and to ensure high reliability. It should be noted that fabrication of detonators is significantly more difficult than fabrication of the explosive charge.

A substantial number of bombing incidents involve the use of incendiary bombs; it is quite impractical to tag the wide range of materials from which incendiary bombs could be fabricated. It may be more difficult, however, to fabricate a reliable delay fuze for an incendiary bomb. In addition, while incendiary bombs may be effective in destroying structures and jeopardizing groups of people, explosive bomb

Figure 4.—Size Comparison of the 3M Identification Taggant and Some Smokeless Powders



tiers offer a better chance of killing, injuring, or intimidating a particular individual.

A significant fraction of the explosives currently used for fabricating bombs is stolen. A taggant program may well increase the theft of explosives; however, additional explosive security could reduce the incidence of theft. Taggants from stolen explosives would not provide a direct clue to the purchaser, but would help law enforcement officers to establish patterns and links between crimes, improving the chances of apprehending the criminals. The bomber who steals explosives further increases the risk of apprehension by committing an additional crime. Finally, taggants could pinpoint locations from which explosives were stolen, providing a guide to tightening security in those places most vulnerable to theft.

Explosives could be purchased on the black market or illegally imported from abroad. Both courses of action subject the bomber to increased risk of exposure from informants or undercover agents in the former case and as a result of smuggling in the latter. Both courses of action would require substantial resources and the ability to plan in advance.

Explosives manufactured before the implementation of a taggant program could be used to fabricate bombs. There is some evidence that a considerable stockpile of explosives currently reside in the hands of criminal bombers, and this stockpile could be expended in the time between legislation and implementation of a taggant program. Acquisition and storage of the explosives for a period of time require considerable advance planning and resources, however, and increase the risk to the bomber of discovery of the explosives. While the use of explosives manufactured prior to a taggant program may be an attractive countermeasure initially, most explosive materials have a limited shelf life. Gels, slurries, and emulsions are generally reliable for less than 1 year; the sensitivity of dynamites tends to increase with age; gunpowders and booster materials have a long shelf life.

Blasting agents, such as ANFO, are not among the explosive materials BATF plans to directly tag. (OTA finds that tagging blasting agents, if it were judged desirable, would greatly increase the cost of a taggant program.) Effective bombs can be fabricated from ANFO. To do so requires a certain level of skill to ensure reliable detonation and the assembly of a number of components, some of which may not be readily available. The risk of premature detonation is small for a bomber with adequate knowledge and patience, but may be significant for bombers without these characteristics. Blasting agents are infrequently used at present in criminal bombings.

The effectiveness of detection taggants can be severely limited by creating a seal between the explosives and the detection taggant sensor so the vapor could not escape the package to trigger the sensor. Such a seal can be constructed with the appropriate industrial materials and equipment, but a reliable seal would be very difficult to fabricate with the resources normally available to individuals. Hence, specialized knowledge, advance planning, and the resources to buy the required material would be needed to defeat the detection taggants.

Detection taggant sensors could be purposely triggered or "spoofed" by placing detection taggants, or other materials so similar chemically to the detection taggant that the sensor could not make the distinction, in nonexplosive materials. If several suitcases or packages within a short period of time triggered the detection taggant sensor for no apparent reason, those operating the sensor might well conclude that it was malfunctioning and disconnect it. It would then be possible to introduce tagged explosives into the protected area. This countermeasure would require that the bomber obtain a supply of the detection taggant material; access to detection taggants could and should be made difficult.

Finally, bombers can turn to other crimes, such as murder, assassination, or kidnapping. These crimes, however, are often not as spectacular as bombings and all involve greatly higher risk to the perpetrators than do bombings. In addition, a direct action against a visible target requires more motivation and a different temperament than does an indirect crime such as a bombing.

Dynamite bomb with nails

Pipe bomb

Molotov cocktail, dynamite, and grenade

Photo credit: U.S. Department of the Treasury

Various types of explosives used by terrorists

OTA consulted numerous explosives experts, all of whom agreed that countermeasures such as these are possible. However, the experts on law enforcement and terrorism which OTA consulted agreed that **criminal bombers would fail to make use of countermeasures even when the necessary knowledge and equipment could be obtained without enormous efforts. However, some terrorists and professional criminals would make use of countermeasures.** The judgment appears to be based on an assessment of the type of personality that is generally involved in this kind of criminal activity. Bombings are currently a low-risk, relatively simple type of criminal activity. Each added element of risk or additional stage necessary to fabricate a bomb will decrease the likelihood of the prospective bomber actually committing the bombing. An instructive analogy is aircraft hijacking. It is possible to smuggle a weapon onto an airplane by some means, but in fact, since the antihijacking program started there have been thousands of weapons found annually by the screening process, hundreds of weapons found abandoned near the controlled boarding gates, and few or no cases of aircraft hijacked with the use of smuggled weapons.

Consequently, OTA believes that countermeasures are not likely to greatly diminish the law enforcement utility of a taggant program despite their potential to do so.

The above discussion has been essentially qualitative, as little quantitative data is available. However, an attempt was made to draw inferences from earlier programs. **The data available from the date-shift program suggests that identification taggants may prove effective in increasing the arrests and convictions of criminal bombers. However, the data base is too small to be more than suggestive. Similarly, data on the reduction of hijackings after the introduction of an antihijacking program suggests that detection taggants would prove an effective deterrent.** The program most directly analogous to the proposed identification taggant program is the requirement that the date and shift of cap-sensitive high explosives be clearly printed on each stick. For undetonated bombs the date-shift code provides the same information as identification taggants would provide for the postdetonation case. No total review of the cases involving explosives recovered from malfunctioning bombs has been conducted. A limited set of 55 cases was examined, however, by BATF. In that sample, six cases were forwarded for prosecution (10.9 percent). That is twice the percent forwarded in cases that did not include date-shift code data. Similar results were obtained by MSA during a review of the BATF data. Of the 15 bombing attempts MSA reviewed, the date-shift code proved useful in 40 percent of the cases, was not useful in 50 percent of the cases, and was of questionable utility in 10 percent. While the results were positive in both cases, the extremely small sample size makes it impossible to draw significant conclusions. IME reported to OTA that manufacturers are seldom requested to appear in court to testify regarding a date-shift trace. In recent years less than 1 percent of the traces requested led to a court appearance.

The most direct analog of the detection taggant program is the antihijacking program initiated in 1972. There was an average of 27 hijackings from domestic origins in the 4 years preceding full implementation of the program. In the next year (1973), hijackings decreased to a single incident and have averaged only four per year since. It should be noted that a number of countermeasures are possible that would evade the currently used magnetometers and X-ray machines. However, seemingly no incidence of the use of these countermeasures have occurred since the inception of the antihijacking program.

Numerical estimates of the numbers of bombers who would be arrested and the number who would be deterred by a taggant program were made by MSA in order to generate input to their cost-effectiveness analysis of the taggant program. The numbers they used in the analysis were a 50 percent increase in the arrest rate (from 8 to 12 percent) and a 5-percent deterrency rate. These numbers are simply guesses and OTA has no data that would allow it to make guesses or assess the accuracy of the MSA guesses.

The above discussion dealt with the utility of taggants for the control of criminal bombers. There exist other approaches to the problem of control of criminal bombers which could be used in conjunction with, or instead of, a tagging program. Some of the methods, however, may be unpalatable or not cost effective. Other approaches, some of which have been implemented in areas facing a more severe bomber threat, particularly from separatist terrorist groups, include:

- alternate detection approaches,
- control of explosive materials,
- better security,
- more coordinated police response, and
- harsher judicial response.

The Aerospace Corp., the Federal Aviation Administration, and the military are currently investigating, or have investigated, a large number of techniques for detection of untagged explosives. Methods investigated have included X-ray fluorescence, gamma ray excitation, nuclear magnetic resonance, both fast and thermal neutron activation, dual energy tomography, detection of the characteristic vapors of explosives, and deactivation of blasting caps. Some of the approaches are promising, although all but the last two would be limited to checked baggage. However, none of the approaches, with the exception of nontaggant vapor detection, has progressed as far as the detection taggant research and most appear to be significantly more expensive, both for the instrument and for personnel to man the instrument. Commercial vapor detectors are currently marketed for explosive detection, but their sensitivities and flexibility fall far short of the goals of the taggant vapor detection devices. Research on the promising approaches should continue. It may be most effective to deploy a detection taggant system in conjunction with one of the other systems.

Control of explosive materials could range from uniform procedures for the purchase of explosives to the total control by the military or police of all explosives, from manufacture to the legal detonation. In some States, explosives are tightly controlled. For instance, in Louisiana all users or transporters of explosives must be licensed by the State police. In some other States, however, explosives may be purchased over-the-counter simply by providing identification and presenting a Federal permit or filling out a form. Uniform tight control would make it more difficult to purchase explosives for illegal use and would be particularly effective in hampering the unsophisticated bombers. Complete control of explosives, to the point of requiring police or military personnel to physically be at the site of a legal use of explosives and be responsible for each detonator (as is the case in Ireland) would essentially eliminate the use of domestically produced commercial explosives in bombings. Sophisticated bombers would be forced to fabricate their own explosives (or purchase "homemade" explosives on a black market) while the unsophisticated bomber would be eliminated. Such a program would entail extremely high costs, however, both in monetary terms and in terms of the disruption to industries that currently use explosives.

Better security is possible both to protect potential targets and to protect explosive materials from theft. It would be possible, for example, to hand-search all checked luggage being loaded on an airplane. In fact, EL AL (national airline of Israel) does conduct such searches. Similarly, it would be possible, although extremely time consuming, to search every person entering the Rose Bowl for the Rose Bowl game. However, detection taggants appear a more reasonable alternative.

Protection of explosives from theft could be improved, however, and may well have to be to prevent a wholesale shift to theft as a source of explosive material if a taggant program is instituted. All of these controls have cost impacts which have not been calculated in this study; a match must be made between their cost and their marginal utility in the face of the current bomber threat. As an example, if the use of military explosives in criminal bombings increases markedly, it may become necessary to counter that threat. Tagging of military explosives would be extremely costly due both to the large amount produced and to the requalification cost of all current munition systems which would be necessary. A reasonable alternative may be to increase the security of military explosives.

A more coordinated law enforcement response to the bomber threat would be effective whether a taggant program were instituted or not. At present, "major" bombings must be reported to either the FBI or BATF. However, no uniform definition of "major" exists. Other agencies, including some State agencies, also collect bombing statistics. Examination of the statistics shows a significant lack of uniformity in what is reported to each, the information available on each incident reported, the retrievability of information from the data bank, and the methods for updating the files. One responsible center to which all bombing information would be required to be reported in a uniform, easily updated, easily accessed format would be an obvious aid to law enforcement efforts against criminal bombers.

Better coordination and communications between the forensic laboratories and the field investigators would also be helpful. Agents in the field are sometimes not sensitive to what information or what physical evidence would be useful to the laboratory. This coordination will be particularly important if an identification taggant program is introduced, as the recovery of the taggants appears to be a laboratory-intensive procedure.

Finally, control of the physical site of the bombing by a single responsible individual would be extremely useful. A major incident may involve several levels of law enforcement agencies, several levels of elected representatives, and other activities such as first aid and fire control. Uncoordinated activity by all these people could well destroy valuable physical evidence. Excessive use of water by firefighters is a potentially serious problem if identification taggants are used, as they might be washed totally away from the bombsite.

The utility of a bomber profile in response to criminal bombers is a particularly sensitive issue with little technological insight available, and is mentioned only for completeness.

Program Implementation

Given the current development state of the identification and detection taggants, a number of options are available regarding the method of implementation of a taggant program. Among the issues are what, if any, taggant program should be legislated; if a taggant program is legislated, what materials should be tagged; what level of tagging should apply; and what is the procedure for making decisions not specifically resolved by the legislation.

One of the first issues needing resolution is what explosives should be tagged. The analyses conducted showed that **criminal bombers tend to use the most readily available source of explosives. Therefore the tagging program with the highest utility would include provisions for tagging of commercial explosives and gunpowders.**

Table 7 showed the frequency-of-use distribution of explosives for bombings, including explosives identified both in the field and in the BATF laboratory. While the completeness of these statistics may be open to interpretation, it is clear that a wide variety of materials are used as bomb fillers. Discussion with both domestic and foreign law enforcement officials has stressed the fact that all types of bombers will use the most readily available source of explosives, although sophisticated bombers would be more likely to limit their use to materials that are efficient for the intended purpose. As an example, a relatively small amount of a powerful explosive was appropriate for the La Guardia Airport bombing, as it would cause extensive damage and be concealable in a relatively small package. The amount of gunpowder needed to do as much damage would occupy a much larger volume and might be noticed. It would therefore not be an appropriate choice for a sophisticated bomber.

If one type of explosive material is not as highly controlled, then bombers will tend to shift toward that material. For that reason, it may be desirable to tag or otherwise control military explosives. Although current statistics show a relatively infrequent use of military explosives in criminal bombings, tagging of commercial explosives may shift the expected future frequency. Similarly, tagging of black and smokeless powders is of critical importance to an overall taggant program.

Some mechanisms to tag blasting agents may also be desirable. However, the cost of directly tagging the agents would be extremely high. The BATF plan to tag the detonators, boosters, and detonating cord normally used with blasting agents may be a reasonable compromise, particularly as blasting agents are now rarely used in criminal bombings and approximately half of the blasting agents are mixed and used onsite the same day.

As indicated above, various levels of implementation of a taggant program are possible, each with an associated cost of implementation. **The most reasonable way to determine the optimum program to implement may be to consider the marginal additional cost of each additional element of utility.** This approach is illustrated in figure 6 where the identification taggant utility function is varied. Qualitative estimates of marginal utility are shown in approximate scale along with quantitative estimates of the cost of implementing a program that would yield that level of utility.

The lowest implementation option would tag cap-sensitive explosives, boosters, detonators, detonating cord, and gunpowders, but not blasting agents. A unique identification taggant would be used for each manufacturer, type of product, and year of manufacture. This program corresponds to the low-level program previously discussed. That level of implementation would directly provide most of the physical evidence information that current methods attempt to provide. However, it would not directly provide a list of last legal purchasers. The relatively modest cost for that program would be approximately $15 million per year,* probably less than is currently expended in an attempt to provide the same information by current means, although the cost would be shifted to manufacturers and users of explosives.

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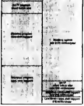
*The cost estimate in this section is for an identification taggant program only.

Figure 5.—Marginal Cost Utility Function


Marginal utility
Marginal cost
High-level program: Blasting agents
BATF taggant (each 10,000 lb)
Medium program: shift/date taggant
Standard program: type, year taggant
Blasting agents add $170 million/year
BATF add batch size add $20 million/year
Medium—shift/date taggant add $10 million/year
Low level—type, year taggant $10 million/year

SOURCE: Office of Technology Assessment.

The next option would be to provide a unique taggant code for each shift of each product manufactured and to keep a record of the movement of explosives from the manufacturer to the last purchasers, in a manner analogous to the date shift code currently marked on the casings of explosives. This option corresponds to the OTA-identified "case" the program and would provide a list of last legal purchasers and additional intelligence information at a program cost increase of approximately $10 million per year.

A further implementation option would be to uniquely tag each 10,000-lb batch of explosives and each 2,000-lb batch of gunpowder. This would lead to a somewhat smaller list of last legal purchasers, which would mean fewer people that must be investigated, as well as a somewhat finer grain of intelligence information. However, the cost increase of $20 million per year would be fairly substantial.

Additional marginal utility could be gained by tagging blasting agents. This would be of value in two cases—the case in which the identification taggants from the detonator and booster used to initiate the blasting agent did not survive (or were not recoverable) from the debris of an explosion, or the case in which a bomb was fabricated that used some other (untagged) means of detonating the blasting agent. There is no body of hard data to indicate the likely frequency of the first condition, while the second condition is certainly possible, almost all bombers capable of detonating a blasting agent without commercial detonators and boosters would also be capable of obtaining or fabricating untagged explosives in the first place. At present, blasting agents are infrequently used for bombings — averaging two BATF sources suggests that blasting agents are used in about 0.5 percent of bombings, and account for a small percentage of the property damage and casualties. Since the cost of tagging blasting agents would be approximately $170 million per year, several times that of all the other elements of a tagging program combined, the marginal utility of doing so appears relatively low.

In short, the implementation of a taggant program would require unambiguous decisions about which materials required taggants, and what the applicable regulations would be. It would be desirable if any legislation on the subject either made these determinations or unambiguously delegated authority to do so.

Given the present state of development of taggants, OTA's data and analyses appear to be consistent with any of three possible courses of congressional action:

1. Pass legislation requiring taggants, and set up a procedure to determine if and when the technical development and testing have progressed to the point where implementation can begin.
2. Defer legislative action on taggants, but encourage (inter alia by appropriating

adequate funding BATF to continue taggant development with a view to consideration of legislation when development and testing are complete.

3. Take no legislative action on taggants and encourage the executive branch to search for other ways of improving the effectiveness of law enforcement against terrorists and other criminal bombers.

If Congress chooses the first of these options, it should recognize that even though the legislation can define precisely what materials would require taggants and provide guidance on the stringency of regulations, there will remain some determinations which it is not yet possible to make:

- When and if an adequate number of successful compatibility tests have been conducted. Particularly pertinent in this regard would be a determination of what constitutes a resolution of the current incompatibility between the 3M identification taggants and one type of smokeless powder or the RDX-based booster material. The 3M identification taggants cannot safely be added to these materials unless such a resolution is accomplished, and neither smokeless powders nor boosters should be excluded from a tagging program.
- When and if a sufficient probability of survival and postdetonation recovery of a given identification taggant has been demonstrated to justify adding that taggant to a given type of explosive.
- When and if a detection sensor has demonstrated adequate sensitivity, low false alarm rate, ease of operation, ease of maintenance, and acceptable unit cost under field conditions to be considered sufficiently available to justify requiring the addition of detection taggants to explosives.
- When and if a detection taggant has demonstrated adequate shelf-life, nontoxicity, and penetrability to be considered available.

In view of the fact that BATF has become the major proponent of the use of taggants in explosives, there is much to be said for entrusting such determinations to an official or procedure outside the Treasury Department.

Chapter III

TAGGANT RESEARCH REVIEW

Chapter III.–TAGGANT RESEARCH REVIEW

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INTRODUCTION

Research into methods to control criminal bombings has been going on for a number of years. One aspect of this research has been concerned with methods of detecting explosives before their detonation, and thus preventing bombings of protected targets. A second aspect has involved the development of procedures and equipment to identify the source of explosives, from either undetonated bombs or from the postdetonation debris, and thus provide information that might aid in the capture of criminal bombers.

Early work in the field was sponsored by the Law Enforcement Assistance Administration (LEAA), the U.S. Postal Service, the Bureau of Mines, the Bureau of Alcohol, Tobacco, and Firearms (BATF), the Federal Aviation Administration (FAA), the Energy Research and Development Administration, various Department of Defense agencies, and a number of companies. The primary efforts in the past 2 or 3 years have been sponsored by the Department of Energy, FAA, and by BATF, with the Aerospace Corp. acting as the BATF project contractor. The BATF/Aerospace work is concerned primarily with the development of tagging materials to aid in the predetonation detection of explosives and in the postdetonation identification of the source of the explosives. The DOE and FAA work has been devoted to the detection of explosives without the use of taggants; some effort has also been expended on that approach by the BATF/Aerospace team.

The purpose of this chapter is to briefly review the research conducted on the detection and identification of explosives. The review will include the development history of the research, a description of the current BATF/Aerospace taggant development program, and a discussion of the survival and recovery of identification taggants. The issues of the safety of adding taggants to explosives, the potential cost impact of a taggant program, and the utility of a taggant program to law enforcement personnel are discussed in detail in the following chapters.

TAGGANT DEVELOPMENT HISTORY

The idea of adding material to explosives to enhance the predetonation detection and the postdetonation identification of explosives has been considered by various military and civil law agencies for at least 15 years. Some of the suggested material, such as radioactive isotopes, would perform both functions; some could only perform one. A number of the concepts which have been proposed during that time are briefly described in the following subsections.

Identification Taggants

Ideas for tagging materials to be used for identification of the source of explosives used in criminal bombings and bombing attempts can be generally grouped into the following four classes:

1. addition of materials that would not survive the detonation but which would provide information if a bomb were recovered undetonated;

2. addition of materials that would physically survive the detonation and be recovered; and
3. addition of materials to the explosives that would be detected in an assay of the debris; and
4. addition of radioactive isotopes.

Predetonation Only

Since 1971 the date shift manufacturer and product have been printed on the cartridge of cap-sensitive high explosives. The manufacturer keeps records by that date shift code and can tell to whom each batch of material was sold. Distributors also are required to keep records of sale. It is possible from the date shift code to compile a list of the legal purchasers of explosives from a lot with the same date shift code. In fact, BATF maintains a National Explosives Tracing Center whose function is to coordinate that activity. A typical trace would start with the recovery of an undetonated bomb by a BATF special agent. He would call into the tracing center with the information, and the data would be forwarded to the manufacturer who would provide the list of consumers or distributors. If explosives from that lot were sold to a distributor, the distributors would be contacted for a list of retail purchasers.

The date shift code information has proven useful in investigations of criminal bombings although its utility is limited to instances where the explosive is recovered before detonation, or in some cases, where a low-order detonation does not destroy the cartridge. In addition, the information is only on cap-sensitive high explosives, and on the packages of detonators, black powder, and detonating cord. No trace data is available for other explosive material such as smokeless powder, individual detonators, or even cap-sensitive high explosives that have been removed from the cartridge.

Smaller amounts of information are given by other systems that do not survive the detonation. For instance, all dynamite legally coming into New York must be red. If dynamite is recovered that is not red, it indicates a purchase not legally usable in New York. This data is not helpful in prosecution tracking of bombers but does assist in control of legal uses of dynamite within New York.

The English apparently use a method somewhat better than the date shift code in that the identifying code consists of colored threads within the explosives. The threads do not survive the detonation but the information content is not lost by discarding the cartridge as is the case with the date-shift code. It may not be possible, however, to encode sufficient information for U.S. needs by that method.

Radiological Tracers

Addition of small amounts of radioactive isotopes to explosives during the manufacturing process is particularly attractive as it provides a mechanism for both identification of the explosive materials from the predetonation debris and a simple detection mechanism. There are a large number of radioisotopes, so an identification scheme could certainly be developed that would provide sufficient unique code species.

The two primary objections to this often proposed solution are public reaction and safety. Given the present widespread antipathy to anything involving radioactivity, it is doubtful if the public would accept such a solution even if there were no safety hazards.

Two potential safety hazards exist, one having to do with sensitization of the explosive molecule and the other with the effects of low-level radiation. Addition of foreign materials to explosives poses a potential sensitivity hazard. However, the amount of radioisotopes required would be far smaller than the material necessary for other tagging mechanisms, so explosive sensitization would probably be no more of a problem than with other types of taggants.

The hazards of low-level exposure to radiation are not well defined; the current trend is toward severe limitation of exposure. Thousands of people come into direct contact with explosives every day at the manufacturers, distributors, and users level, so a large amount of people would have some exposure. Primary concern would be at the manufacturing level where workers would have more continuous exposure than, for instance, a user. Aside from the adverse psychological effect the use of tracers might have on such workers, and the possible long-term effects of low-level exposure, there would be a large cost impact due to the need for specially trained personnel as well as storage, handling, and decontaminating equipment. If it were necessary for the Nuclear Regulatory Commission to control the shipment of the explosives and to license and otherwise supervise all explosive users, additional major costs and inconvenience would ensue.

A final drawback is that reading of the information encoded in the postdetonation debris would be a fairly complicated laboratory procedure involving sample preparation, radiation counting, and radioisotope identification. Only a limited number of laboratories in the country have the trained personnel and facilities; police forensic laboratories are not among them.

Chemical Assay

A number of approaches have been proposed that have in common the addition of chemicals to the explosives that would be recovered from the postdetonation debris and be identified by a laboratory assay of the debris. While the number of chemical materials is almost limitless, a successful chemical taggant must have the following properties:

- inertness,
- nonsensitization of the explosives,
- not present in background material,
- able to survive the detonation,
- long-term stability,
- not a health hazard, and
- sufficient variation must be possible to form a large number of unique codes.

The chemical taggant with which the greatest amount of research has been conducted was developed by the Ames Laboratories in the early 1970's. In this method, rare earths were added to explosives as oxides or as nitrates in ethanol solutions. By using several rare earths and by varying concentrations, a sufficient number of unique codes could be constructed. The taggants were recovered from the debris with ethanol-dampened cotton swabs. The swabs were then assayed in the laboratory by ion exchange methods; analysis was accomplished by X-ray excited optical luminescence techniques.

Drawbacks to the Ames taggants included sensitization of the explosives by the ethanol carrier, a high background level pertaining to detonations taking place near or on the ground, and a rather specialized laboratory procedure necessary for the taggant assay and identification.

Physical Taggants

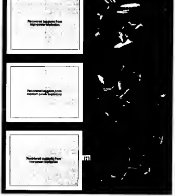
This class of taggants is designed to survive the detonation in its original physical form, to be separated from the debris, and to be decoded either in the field or in the laboratory. Several types of materials have been suggested. Physical taggants must meet the same requirements as the chemical taggants; however, in addition to physical survival, the number of serious candidates is somewhat limited. Three taggants remain promising candidates.

3M COLOR-CODED TAGGANT

More research has been conducted with the 3M identification taggant than with any other. It is the baseline taggant proposed by BATF for implementation if a taggant program is legislated, and is the taggant used for the OTA cost, safety, and utility analyses.

The taggant consists of an irregular chip of thermosetting melamine alkyd, approximately 0.12 mm thick and about 0.40 mm in its greatest dimension. Figure 6 shows the eight-layer construction. Variation of the sequence colors provides the necessary library of codes. A total of approximately 1 million unique codes is available when allowances are made for certain forbidden adjacencies (colors too difficult to distinguish) and other restrictions. One face of the taggant visibly fluoresces when illumi-

Figure 6.—3M Color-Coded Identification Taggants


Recovered taggants from high-power explosion
Recovered taggants from medium-power explosion
Recovered taggants from low-power explosion
m

nated with black light (366 nanometers) as an aid to recovery, either in the field or laboratory. The other face contains iron powder, allowing the taggant to be picked up by a magnet, another recovery aid.

In theory the taggant can be recovered from the debris by use of a magnet and a black light, read in the field by a low-power microscope, and traced through the BATF tracing center. In fact, laboratory separation may be needed in most bombings; the recovery and laboratory procedures are quite simple, however, and can be performed in the field with little equipment and training.

Several variations of the basic concept have been tried, some including a polyethylene encapsulant and some including slightly different chemical and physical properties of the individual layers. The safety, survivability, and identification aspects are discussed in great detail elsewhere in this report.

WESTINGHOUSE CERAMIC TAGGANT

The Westinghouse taggant consists of a mixture of rare earth compounds, bound together into a ceramic-like particle whose appearance is similar to a grain of sand and whose largest dimension is approximately 0.2 mm. Each of the rare earth compounds fluoresces at a characteristic wavelength when illuminated by ultraviolet radiation (325 nanometers). A scanning monochromometer is used to read the wavelength of the various rare earth compounds, and thus to identify the taggant code. The 10 rare earths that have been evaluated and their characteristic emission wavelengths, are:

	Nanometers
Strontium chlorophosphate: europium	447
Yttrium vanadate: thulium	476
Yttrium phosphate cerium: terbium	546
Yttrium vanadate: erbium	554
Yttrium vanadate: dysprosium	575
Yttrium vanadate: samarium	610 646
Yttrium vanadate: europium	663
Yttrium oxysulfide: europium	626
Strontium fluorophosphate: antimony, samarium	562
Strontium fluoroborate: europium	376

As in the 3M taggant, the Westinghouse taggant incorporates a spotting phosphor which fluoresces in the visible range when illuminated by shortwave ultraviolet radiation (254 nanometers) and magnetic particles, both of which assist in the recovery process.

Due to the limited number of rare earth compounds available and the fact that the individual components are not ordered like the 3M taggant layers, the library of possible codes is only approximately 3,000 even with three distinct spotting phosphors. Use of different concentrations or pairing of two different taggants to form a unique species can significantly increase the library, with approximately 600,000 codes available for the present taggant version.

A significant number of compatibility tests have been conducted with the taggant, as have a small number of survivability/recoverability tests. Due to the ceramic nature of the taggant, it is extremely survivable and does not thermally degrade in high-energy explosives (such as boosters) as has the 3M taggant. In addition, since the rare earth doping is homogeneous throughout the material, the full code can be read from even a small recovered taggant chip. The Westinghouse taggant is extremely gritty and has been shown to sensitize explosives if not encapsulated in a polyethylene coating.

No additional effort is currently underway with the Westinghouse taggant due to a Westinghouse concern over liability should some taggant not be fully encapsulated and thus cause sensitization of an explosive material. From the limited data available, it would appear that the Westinghouse taggant shows interesting potential, particularly due to its high survival rate, although care must be taken to ensure 100-percent encapsulation. In addition, some further limitations are imposed by the relatively small code library available and by the rather complex laboratory identification procedure required.

CURIE POINT TAGGANT

The Curie point taggant consists of a collection of five distinct ferrites packaged with an ultraviolet sensitive spotting phosphor in a binder of potassium silicate. Ferrites exhibit the property that their ferromagnetism disappears when the temperature of the ferrite is raised above a specific temperature designated the Curie point temperature. Identification of a particular taggant is thus accomplished by placing the recovered taggant in a temperature-controlled chamber and recording the magnetism as a function of temperature.

Approximately 50 ferrites have been identified whose Curie point falls in a laboratory practical temperature range. The 50 ferrites, used in combinations of 5 at a time, yield a library of approximately 2 million unique species.

As the taggants are ceramics, their survivability in high-energy explosives, such as boosters, should be good. Very preliminary tests have demonstrated the survivability of the taggant in boosters and high power commercial explosives such as Power Primer.

The Curie point taggants share the potential sensitization problem of the Westinghouse taggants, and must therefore be encapsulated with 100 percent certainty. The Curie point taggants have another serious drawback: magnetic separation from powdery materials such as gunpowders and powdery dynamite would be an obvious simple countermeasure.

Summary

The 3M taggant, which has been the most thoroughly researched identification taggant, appears to be the most viable candidate, although the Westinghouse taggant exhibits a good deal of promise at this early stage of development. The other candidates exhibit technical, cost, countermeasure, or public acceptance problems, or require elaborate laboratory apparatus and analysis to yield the identification code. However, as other sections of this report make clear, the 3M taggant is not yet fully developed or tested, and could not be generally used unless and until several remaining problems are resolved.

Detection Taggants

Four general types of detection tagging approaches are described in the literature, including:

1. radioisotopes,
2. vapors,
3. electromagnetic (EM) taggants, and
4. activation of nonradioactive isotopes.

Radioisotopes for use as detection taggants possess the same drawbacks as they do for use as identification taggants; the above discussion need not be repeated here.

Electromagnetic taggants incorporated into a detonator, such as the passive harmonic radar taggant investigated by the Aerospace Corp., offer the possibility of detection at a distance with a relatively low rate of false alarms. All of the concepts so far proposed, however, can be easily defeated by wrapping explosives in metal foil. In addition, inclusion of such devices would probably have a significant effect on the procedures used to manufacture detonators, on detonator cost, and significant false alarms could be caused by common diodes from radios, calculators, and other electronic instruments.

A variation of the idea of electromagnetic taggants has been proposed, called detonator deactivation. In the concept, a reed switch is connected in series with a detonator bridge wire. Illumination of the detonator by a switchable electromagnetic source would cause the reed to open. A number of methods are possible to ensure that the reed could not be subsequently closed. The advantages of the concept are twofold:

- the necessary illuminator could probably be made quite inexpensively, allowing it to be used to protect far more targets than would be possible with other detector concepts, and
- the deactivation process is passive — no operator is necessary.

Disadvantages include the fact that deactivation rather than detection of bombs would offer no help in finding the would-be criminal them both significant (and possibly costly) impacts on current processes of manufacturing detonators; and the risk of accidentally deactivating detonators, resulting in their failure for normal use. No research beyond initial conceptualization has been conducted for the concept.

An interesting taggant concept has been suggested by the Franklin Institute based on the idea of using Mossbauer active isotopes as taggants. The technique involves the addition of nonradioactive trace taggants to explosives followed by the gamma ray excitation of the Mossbauer isotopes and the measurement of the characteristic absorption spectrum of these taggant isotopes. The Mossbauer effect has been measured in numerous common elements, including iron, tin, and nickel. In a Mossbauer isotope, gamma rays, whose energy corresponds to the transition energy between nuclear levels, may be resonantly absorbed upon excitation, producing a sharp absorption spectrum characteristic not simply of the Mossbauer element but of the chemical compound of the element. This effect is due to the small perturbations of the nuclear levels by the surrounding electrons. For instance, a taggant in a chemical compound not found in nature or used in industry would be manufactured. Due to the low excitation level required, little shielding of the source would be necessary.

Mossbauer taggants are simply a concept at this stage, however, so little judgment can be made of its practicality and safety in explosives. An Aerospace Corp. analysis questions the practicality of the technique. A significant limitation in the use of the Mossbauer and other activation techniques is that they cannot be used to search people due to the activation radiation.

A number of other activation taggant techniques have been suggested, including the doping of explosives with material that would enhance the effectiveness of X-ray or similar devices. These concepts all lack specificity, however, and could cause the X-ray to be triggered by many common items, resulting in an unacceptable false alarm rate.

Vapor Taggants

Vapor taggants have received the bulk of the research on detection taggants. Vapor taggants share the common taggant requirements of stability, inertness, compatibility with explosives, and absence from natural materials. In addition they must have a vapor pressure sufficient to produce enough molecules to be sensed but not so high that a large initial mass would be required to ensure continued operation when placed in explosives that have a shelf life of several years. They must have a relatively steady molecule emission rate over a 5- to 10-year shelf life, must not produce an environmental hazard, and must not readily adhere to surfaces with which they are likely to come into contact.

Several hundred different vapor sources have been considered, with almost 200 having been investigated in the laboratory. Avenues of approach have included the use of disproportionating salts, the direct adsorption of vapor taggants into the elastomeric plug material of detonators, and the microencapsulation of taggant materials.

DISPROPORTIONATING SALTS

A number of the salts of weak acids and bases, such as boron trifluoride adduct compounds, disproportionate or separate into two or more constituent parts, some of which sublimate at room temperatures, theoretically providing a possible stable vapor emission source. Tests conducted by the Aerospace Corp. indicated that no compounds investigated had the proper balance of vapor pressure, emission rate, desired lifetime, and projected detection limit by a sensor to allow the use of a sufficiently small amount of taggant material. It is possible to control the emission rate of a high vapor pressure salt by the use of a microencapsulation membrane. Use of such a membrane allows the consideration of a large number of more easily handled liquid taggants, however, as described below.

ELASTOMERIC ADSORPTION OF VAPOR TAGGANTS

The adsorption of the vapor detection material directly into the elastomer used to form cate the end plug of detonators offers a number of advantages, including removal of the necessity for additional steps or changes in the detonator fabrication process. Research has therefore been conducted to evaluate the effectiveness of various elastomer taggant pass. Taggants evaluated include sulfur hexafluoride and halogenated alkanes, amines, carbolan, esters, and ketones. A number of combinations appear feasible, although useful lifetimes may be shorter than the 5-year minimum desirable. A more severe limitation, however, is that the elastomerically adsorbed taggants would be useful only on detonators, and possibly with detonating cord. None of these taggants appears to be as successful as other candidates when microencapsulated for use with other explosive materials. Use of separate taggants for detonators for other explosives would lead to the development of two sensors or to the requirement for dual-mode sensing in a single sensor, an unnecessary sensor development constraint.

MICROENCAPSULATED VAPOR TAGGANTS

Approximately 140 vapor materials have been screened in the laboratory as candidate microencapsulated vapor taggants. In addition, several hundred other materials were rejected after a thorough analytical review. Five candidate perfluorinated cycloalkane compounds have been extensively tested and have successfully completed barrier penetration, mutagen toxicity, and atmospheric impact testing. The five candidate vapor taggants and their chemical properties are shown in table 16.

A parallel research effort has been underway to find an appropriate microcapsule material. The optimum material would be inexpensive, easy to use with the candidate taggant materials, compatible with the explosive materials, and form membranes that account for only 10 to 20 percent of the microencapsulated taggant weight. Figure 7 shows a photograph of a candidate microencapsulated vapor detection taggant with a needle to indicate relative size.

Emission rate studies are currently underway with a number of membrane materials. Early tests were very encouraging; a number of more recent test results show variations in emission rate from lot to lot and as a function of ambient relative humidity and temperature. Tests have not yet started on long-term emission behavior, especially in the presence of explosives. Tests have only recently started on the compatibility of explosive materials with either the taggant vapors or the membrane materials.

Summary

Although a wide range of detection taggant materials have been proposed, the need for long life, stability, specificity, and absence of easy countermeasures has caused the bulk of these to be rejected, at least given the current state-of-the-art. The most promising concept is the microencapsulation of perfluorinated cycloalkane compounds, although the direct adsorption of taggants into the detonator plug elastomer appears promising for that application. A number of preliminary tests have been conducted with five candidate taggants; compatibility testing has just been initiated. Detonator deactivation is a possible alternate approach, although little research has been accomplished.

Table 16.—Candidate Vapor Taggant Properties

Chemical name	Abbreviation	Empirical formula	Molecular weight	Boiling point °C	Melting point °C	Specific gravity	Vapor pressure (300° K = 27° C)
Perfluoro-1,2-dimethylcyclobutane	PDCB	C_6F_{12}	300	45	-32	1.67	549
Perfluoromethylcyclohexane	PMCH	C_7F_{14}	350	76	-37	1.79	96
Perfluoro-1,3-dimethylcyclohexane	PDCH	C_8F_{16}	400	102	-70	1.85	35
Perfluorodecalin	PFD	$C_{10}F_{18}$	462	142	-10	1.93	8.8
[illegible]	L-4482	[illegible]	440	119	3	1.59	18.5

SOURCE: The Aerospace Corp.

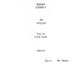
Figure . Microencapsulated Detection Taggants Shown With a Needle to Indicate Size

Detection Taggant Sensor Systems

The development of a system to detect the emitted vapors is proceeding in parallel with the development of vapor-emitting detection taggants. A schematic block diagram for the operation of such a system is shown in Figure 8. Air from the vicinity of the item being inspected is collected and delivered to a sensor after first being conditioned. The sample collector can simply consist of a gust of air for inspection of boarding passengers, or can include a small pressure pulse to a piece of checked baggage to introduce more of the air from the interior of the baggage into the air sample stream. For some of the concepts the free oxygen and water vapor must be removed prior to insertion of the air into the sensor. If the vapor taggant is present, an alarm indication is registered; if none is present, then the item passes through with no delay. A detailed procedure has not been developed to deal with alarms, but the procedure would probably include a recycle through the sensor to eliminate the chance of an equipment transient being responsible, followed by a suspected bomb disposal procedure if the alarm persists.

Work is progressing on three candidate detection sensors. Very little effort has been expended by the Aerospace Corp. on the other elements of the system, although some preliminary design identification work has taken place on the air sampling process and on methods of enhancing the original sample. A U.S.

Figure 9.—Detection Taggant Sensor System Block Diagram



SOURCE: Office of Technology Assessment

Customs Service device has been tested for instance which exerts a gentle force on baggage, causing an exhalation of the baggage interior air into the sampling network.

The three candidate detection sensors are, in order of increasing complexity and cost, the continuous electron capture detector (CECD), the ion mobility spectrometer (IMS), and the mass spectrometer (MS). Figure 9 shows a schematic diagram of the operation of IMS. Gas is introduced from the sampling device into the conditioner. After the free oxygen and water vapor are removed, the sampled gas molecules are drawn into the ionization region where many molecular species, including the taggant molecules if present, form negatively charged ions. The negative ions are then gathered and injected into a drift tube where an electric field causes them to flow against a counter-flowing drift gas stream. By virtue of the ion molecule reactions between the negative ions and the neutral drift gas molecules, the ions are separated into spatial clumps of like species. Each species, depending on the strength of the ion-molecule interaction, traverses the length of the drift tube in a different length of time so that one can turn on or gate the detector to respond only to a specific molecular species or group of species such as the taggant vapors.

The taggant molecules being considered all have long drift times and are easily separated from common gases in the IMS. Additional specificity is gained by the toughness of the taggants; most other large molecules fragment in processing through the detector.

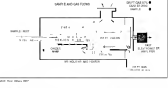
IMS devices have been commercially available for approximately 5 years, with about 40 currently in use for various applications. Tests have been run with a commercial IMS unit at airports to examine ambient air for the presence of molecules in the critical drift time region; no molecules which would have triggered a false alarm were detected.

While the laboratory tests are promising, it is not possible to extrapolate to estimates of IMS performance in the field in a real-life environment, when maintained by normal airport maintenance people, and when using an internal calibration source.

CECD can be conceptually viewed as an IMS device without a drift tube. It simply consists of the conditioner and reaction chamber; the decrease in current in the reaction chamber is a sign that the taggant molecules are present and have been ionized. As described, CECD would have less specificity than IMS, and would probably be triggered by a wide range of interference sources. The key to the device is in the conditioning chamber; the chamber is a catalytic reactor that contains hydrogen gas and palladium metal plated onto a number 5A molecular sieve and operating at 140° C. The reactor removes oxygen and water vapor, fractures some other potential interference sources, while still others are removed by reduction or combustion. The number of molecules that will survive the conditioning chamber is limited, but the taggants may well not be the only survivors of the passive screening process.

CECD devices have been used as a laboratory instrument by the Brookhaven National Laboratory for the past several years. A broad

Figure 3—Cutaway View of the PhemtoChem 100 Sensor Cell in the Ion Mobility Spectrometer



SOURCE: [illegible] 1977

board device was recently shown to be quite successful in detecting vapor-tagged dummy blasting caps in baggage on a conveyor belt.

The MS is a standard laboratory instrument easily capable of resolving the taggant molecules from other species. Current MSs, however, are usually expensive, relatively sensitive laboratory instruments. The challenge is to design and develop a low-cost, field-usable instrument that will detect taggant molecules in a parts-per-trillion concentration level.

The limited laboratory testing of detection sensors that has taken place has demonstrated that the technology exists for sensors which could detect the taggant vapors. These tests have not yet demonstrated, however, the ability of the instruments to distinguish between the taggant molecule and similar molecules which may exist in the environment or may be deliberately introduced into the environment as a countermeasure. It has also not been demonstrated that any of the instruments can successfully detect the taggants in the required parts-per-trillion concentration level under field-use conditions.

The time required to develop instruments of this type is a pertinent subject for discussion, even assuming that the technical problems can be solved. The milestones in a development process include:

- demonstration of technical feasibility
- generation of specifications for a prototype
- prototype development
- generation of specifications for the instrument
- pilot production of the instrument, and
- full-scale production.

None of the detection sensor concepts has yet passed the technical feasibility demonstration milestone. The only time estimate which has been made is an extremely optimistic estimate of 14 months from demonstration of technical feasibility to completion of a prototype. The estimate assumed no technical, contractual, or other problems, and may well be off by a factor of two. Given the fact that these instruments would be produced in quantity (up to several thousand), must be self-calibrating, maintained by routine maintenance people and detect at the state-of-the-art parts-per-billion level. It is unlikely that production could be underway in less than 5 years.

If the instruments can be developed to perform as desired, however, they should be quite effective, the operating costs and false alarm rates would be negligible while the detection rate would assure essentially no successful penetration of the sensor system.

UNTAGGED DETECTION

Three general methods have been explored for detecting explosives that do not have detection taggants added. These include vapor detection of the characteristic vapors present in the explosives, the use of differential gas chromatography, and the use of excitation induced emissions. Some of the specific techniques investigated are briefly discussed below.

Vapor Detection

A great deal of research effort has been expended in the field of detection of the characteristic vapors emitted by explosives. Table 17 shows the physical properties of the vapor phase of a number of explosive materials while table 18 shows some of the methods used to detect the explosive vapors. Much of the effort has been concerned with characterizing the vapors that are present in explosives, looking for vapors common to a number of explosive materials, and quantifying the problems of vapor detection. While the equilibrium concentrations of the vapors shown in table 17 are within the detection capabilities of much of the instrumentation depicted in table 18, several problems limit the utility of vapor detection.

One of the primary problems is the lack of a common vapor in the various explosive materials. Either nitroglycerine or EGDN is often present in dynamites, and in smokeless powders, but neither are present in the other explosive materials used in criminal bombings, such as gels, slurries, black powder, detonators, and boosters. A detection device would then have to be able to detect a significant variety of vapors (and thus either be quite slow or expensive) and would be subject to a high rate of false alarms as it could be triggered by the spectrum of materials that would be screened by the vapors from the common explosive materials.

A second significant problem is the amount of vapor actually available for detection. While the equilibrium concentrations of the vapors are high enough to assure detection, the actual amount of vapor present will be significantly degraded by the container that contains the explosive, particularly if an effort is made to create a vapor barrier. The explosive vapors do not have the properties of penetration and nonadsorption of the vapor taggant materials discussed in the previous section. Concentration of the vapors could help alleviate the problem, but that might cause sufficient concentration of ambient interference molecules to generate a high false alarm rate.

These defects must be balanced against the major advantage that detection of the characteristic vapors of explosives has over the detection of tagged vapors—only those explosives that have been tagged can be detected if the sensors are designed to look for the vapor taggant.

As shown in table 18, a large number of physical principles have been used to detect the vapors. The most successful, however, are the ionization mechanisms exploited for detection of taggant vapors. Continued research is primarily devoted to these sensors.

Animal detection deserves a specific comment. Although less sensitive than the other

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From "Explosive Vapor Detection Instrumentation," by J. R. Hobbs, printed in the Proceedings of the Electro Professional Program, New York, April 1979.

Table 17.—Vapor Pressures of Selected Explosives

Compound	Molecular weight	Temperature °C	Vapor pressure mm Hg	Composition g/cm³	Mole fraction (V.P./760)
EGDN—ethylene glycol dinitrate	152	25	2.8 × 10⁻²	2.3 × 10⁻⁷	37 ppm
NG—nitroglycerine	227	25	2.4 × 10⁻⁵	2.9 × 10⁻¹⁰	32 ppb
PETN—pentaerythritol tetranitrate	316	25	5.4 × 10⁻⁹	9.2 × 10⁻¹⁴	7 ppt
AN—ammonium nitrate	80	25	5.0 × 10⁻⁶	2.2 × 10⁻¹¹	7 ppb
DNT—dinitrotoluene	182	25	1.4 × 10⁻⁴	1.4 × 10⁻⁹	184 ppb
TNT—2,4,6-trinitrotoluene	227	25	3.0 × 10⁻⁶	3.7 × 10⁻¹¹	4 ppb
RDX	222	25	1.4 × 10⁻⁹	1.7 × 10⁻¹⁴	2 ppt

SOURCE: J. C. Dahn, Explosive Vapor Detection Instrumentation.

Table 18.—Explosive Vapor Detection Techniques

Optical	Ionization	Animals	Other
Infrared	Electron capture	Bioluminescence	Piezoelectric
Ultraviolet	Gas chromatography	Dogs	Thermionic
Microwave	Mass spectrometry	Gerbils	Condensation nuclei
Fluorescence	Gas chromatography/ mass spectrometry	Enzymes	
Laser raman	Plasma chromatography		
Two-photon absorption			
Chemiluminescence			
Laser optoacoustic			

SOURCE: J. C. Dahn, Explosive Vapor Detection Instrumentation.

sensors (by orders of magnitude), animals have some potential advantages. If small animals such as rats and gerbils can successfully detect explosive vapors, then the cost of an animal backup system would be quite small. Dogs are more expensive to train and work with, but have the advantage of being used for other law enforcement work such as patrols.

Differential Contrast Radiography

Differential contrast radiography takes advantage of the fact that different materials attenuate the strength of a source to a different degree, depending primarily on density and atomic number. Commercial X-rays and the imaging X-ray detectors used to screen hand baggage at airports work on this principle. Similar devices have been fabricated using gamma radiation and neutrons as the beam source. This method is quite effective for detecting materials whose density is significantly greater than other materials in the environment, such as a steel gun (specific gravity of 7.8) in a briefcase containing books or clothes (specific gravity less than 1.0), but is much less effective in detecting smaller differences in density. Most dynamites have a specific gravity of approximately 1.5; booster materials and tertiary explosives are slightly higher (up to 1.8); gunpowders have a bulk density of less than 1.0.

The current imaging systems at airports are operator-monitored and therefore dependent on the ability of the poorly trained operator to discriminate small density differences. Most recent research has been concerned with automating the radiographic scanning systems. Due to the wide span in density of explosive materials and the large density overlap between explosives and other materials, it is necessary to include other means of discrimination in the detection algorithm. Shape is the other discriminant currently used. The pattern recognition algorithm in a computer reacts when the proper density and shape pattern are detected. Such a system is sensitive to orientation, arrangement, and shape of the high explosive as well as to the mass of the high explosive. The breadboard laboratory models so far developed can incorporate only a limited number of shape-density combinations and are able to detect only certain shapes of C-4 explo sive and certain shapes of dynamite bombs. While they could detect a 2-lb C-4 charge shaped like a package of bullets, they would not detect the same charge shaped as a sphere, cylinder, pancake, or sausage or even another explosive of slightly different density shaped in the bullet package shape. As the devices scan from only one axis, a 2-inch-thick slab with a specific gravity of 0.5 looks much like a 1-inch-thick slab of density 1.0. Such a lack of specificity not only generates high false alarms, but explosives arranged in an unusual shape would not be detected.

Two avenues of approach are being pursued to try and alleviate the discrimination specificity problem. The first is to use more than one energy level for the radiation source. Each type of material has a different opacity to different radiation energies. If more than one energy source is used to illuminate the object, then additional information about the material is gained. Some recent work indicates substantial gains in information are possible using two carefully chosen energy levels.

The second approach is to illuminate the package along more than one scanning direction. The information gained can help generate a better idea of both the package shape and its density. In a technique called tomography the images formed by scanning from several directions are computer processed and used to generate a three-dimensional image of the package in the computer. Any two-dimensional projection can then be generated as well as an accurate density value. This image can be compared to all possible conformations of common explosive materials by the computer, yielding a much higher probability of detection as well as a lower false alarm rate. Aerospace Corp. is currently sponsoring research on dual-energy tomography, which would combine the additional information available from both multiple directional scans and multiple x-energy scans.

Excitation-Induced Emissions

Many materials absorb radiation of a specific wavelength and subsequently emit an induced radiation whose energy may be a function of the elemental (isotopic) composition of the specific compound due to the interaction of the orbital electrons with the nuclear material. The Mossbauer isotopic taggants described in the previous section were an example. Several methods of utilizing induced emissions have been investigated for detection of explosives, including the use of thermal neutrons, X-ray fluorescence, and nuclear magnetic resonance.

The thermal neutron detection concept utilizes the capture of thermal neutrons by nitrogen with the subsequent prompt emission of a 10.8 MeV gamma ray. Explosives are rich in nitrogen and should be easily detected in an unshielded suitcase, but so are a large number of other materials such as wool, orlon, nylon, and leather. Coupling the system to a pattern recognition computer might be sufficient to discriminate between a solid block of explosives and a couple of cotton sweaters (although test results were marginal), but discrimination between these sweaters and a bomb in which single dynamite sticks are connected by detonating cord, for instance, would be extremely difficult. Processing times for this concept are also rather long for efficient transport of baggage.

Nuclear magnetic resonance (NMR) is a technique with considerably greater specificity. In NMR detection an applied radio frequency magnetic field with the correct frequency induces energy level transitions in hydrogen with the subsequent prompt reradiation of energy in a manner specific to the chemical compound containing the hydrogen. A sensor tuned to receive the signals that would be emitted by the hydrogen in various explosive materials could theoretically detect any type of explosive even when present in small quantities. A major problem with the utilization of this technique for explosives detection would be the fact that metal interferes with the NMR performance, thus shielding the explosive. The unit would also have to be quite large (and thus expensive); the magnet for an NMR unit large enough to scan a suitcase would weigh several tons. Another problem is the rather slow response cycle time.

Summary

A number of techniques have been described for the detection of untagged explosives. Preliminary testing has been accomplished on most of the techniques discussed; few concepts have progressed as far as the studies on detecting vapor taggants, with the exception of the use of animals to detect the characteristic vapors of explosive materials. Some explosive detection devices are currently on the market, although their performance is not satisfactory. Other techniques have been suggested and extremely limited testing has been conducted on some of them. All of the untagged detection concepts contain significant problems in terms of adaptation to field use. Instrumentation for many of the concepts would be large and expensive, many are easily countermeasured, and none, with the exception of the vapor detection devices, could be used to screen passengers.

Granting the many problems in nontagged detection, there may still be a significant potential payoff if an explosive detection instrument or technique could be devised that could detect all explosives, not just those to which taggants had been added.

CURRENT BATF/AEROSPACE TAGGANT PROGRAM

In 1976, the Aerospace Corp. was designated by BATF as the system technical manager of the taggant program. Prior milestones leading to the current taggant program development effort were:

- 1973—Joint establishment by BATF and FAA of an ad hoc committee on explosives tagging.
- 1973—Formation of the Advisory Committee on Explosives Tagging chaired by BATF for coordination of Federal agencies involved with tagging and the control of the illegal use of explosives.
- 1973—Lawrence Livermore Laboratory study to determine feasibility of identification tagging with Aerospace Corp. acting as the program technical manager and LEAA as sponsor.
- 1976—National Implementation Model and Pilot Test Plan for Identification Tagging developed by the Aerospace Corp. under contract to the Bureau of Mines.
- 1977—Aerospace Corp. designated the system technical manager for the tagging program by BATF.

Since 1977, Aerospace has been engaged in an ongoing program of analyses and testing to develop identification and detection taggants and to demonstrate their use in explosive materials. Details of the taggant and sensor development programs were given above; the status of the compatibility testing program is detailed in chapter V; the status of survivability and recovery testing is reviewed in the following section and in appendix C; some details of the analysis and pilot testing status are reviewed in chapter V. This information is briefly summarized below, as is a description of the BATF implementation philosophy.

Program Status

The status of the taggant development effort is summarized in table 19 for identification taggants and in table 20 for detection taggants. In the tables, "Technical feasibility" refers to a demonstration or analysis which indicates the concept is feasible. "Technical readiness" refers to a demonstration or analysis that the concept will work in the manner suggested, and "Practical readiness" indicates that the full spectrum of analyses and tests has been completed which shows that the concept is ready for full-scale implementation.

The ability of the 3M Co. to produce the color-coded taggants has been demonstrated

Table 16.—Identification Taggant Program Status

Accomplished			Planned or required		
Technical feasibility	Technical readiness	Practical readiness	Technical feasibility	Technical readiness	Practical readiness
Unmodified taggant development					
• Initial survivability/compatibility testing • Environmental impact assessment • Health impact assessment	• Pilot production compatibility	• Leadtime study			• Tagging period/testing Optimize lines
Cap-sensitive packaged explosives (dynamite, water gels, slurries, and emulsions)					
• Initial compatibility testing • Initial survivability testing • Manufacturing process reviewed and practicality assessed	• Online tagging demonstrated • Tagging methods selected/evaluated	• Pilot test production-level tagging • Recordkeeping methods demonstrated	Comprehensive compatibility testing	• Comprehensive survivability testing	Analysis/optimization of approach Long-term compatibility
Black powder					
• Initial compatibility testing • Hot/cold survivability testing • Manufacturing process reviewed and practicality assessed	• Online tagging • Additional compatibility (electrostatic) testing • Transportation/vibration segregation testing	• Some ballistics testing	Comprehensive compatibility testing	• Comprehensive survivability testing	• Ballistics testing • Online tagged survivability testing Long-term segregation • Long-term compatibility
Cast boosters					
• Initial compatibility testing • Initial survivability testing • Manufacturing process reviewed and practicality assessed	• Online tagging • Tagging methods selected/evaluated		Solution of problem posed by reactivity (self presumed incompatibility) with Composition B Comprehensive compatibility testing Recovery testing	• Comprehensive survivability testing	• Pilot testing production-level tagging • Long-term compatibility • Comprehensive survivability testing • Recordkeeping methods demonstrated • Analysis/optimization of approach
Detonating cord					
• Taggants added by hand; initial survivability demonstrated • Manufacturing process studied and tagging practicality assessed			Recovery testing	• Tagging station development • Online tagging	• Comprehensive survivability/compatibility testing • Pilot testing
Smokeless powders					
• Hand-mix survivability testing			Solution of problems posed by reactivity (and presumed incompatibility) with [illegible] • Compatibility and hazards analysis Compatibility and acceptance testing	• Evaluation testing of sequential lots • Production hazard and acceptance testing • Comprehensive survivability testing • Online tagging	• Ballistics testing • Pilot testing
Detonators			Full range of tests and process evaluation required		

SOURCE: Office of Technology Assessment.

Table 20.—Detection Taggant Program Status

Accomplished			Planned or required		
Technical feasibility	Technical readiness	Practical readiness	Technical feasibility	Technical readiness	Practical readiness
Microcapsule development • Production and evaluation of test batches • Health and atmospheric impact assessment			• Initial compatibility studies • Complete health and atmospheric impact assessment • Taggant selection	• Pilot production of capsules	• Competitive award /for/ time studies • Development and testing of production • Full-scale production capability
Dynamite, slurries, and water gels • Compatibility testing initiated	—	—	The full range of analyses and tests detailed in identification taggants must be accomplished for the detection taggants, with the exception of postdetonation survivability and recovery testing.		
Black powder • Compatibility testing initiated	—				
Cast boosters • Compatibility testing initiated	—	—			
Smokeless powder • Compatibility testing initiated	—	—			
Detonating cord	—				
Detonators • Compatibility testing initiated					
Continuous electron capture detector • Successful breadboard demonstration • Instrument characterization (initiated) • Calibration system (initiated)	—	—	Instrument characterization (in process) Calibration (in process)	• Design prototype • Fab and lab test evaluation • Aerospace lab test	• Prototype shelf test • Prototype design changes • Final production drawings • Production pilot release • Production pilot complete • Field support function setup • Training and field test
IMS detector • Initial feasibility studies			Demonstration (imminent)	• Design prototype • Fab and lab test prototype • Aerospace lab test Prototype field test	• Prototype design changes • Production drawings • Manufacture and checkout engineering • Production pilot release • Production pilot complete • Support functions setup • Training and field test
MS detector • High-cost laboratory system testing • Development and breadboard demonstration—in process			Development and breadboard demonstration to be completed	Prototype design fabrication and test	• Prototype design changes • Production drawings • Manufacture and checkout engineering • Production pilot release • Production pilot complete • Support functions setup • Training and field test

SOURCE: Office of Technology Assessment.

although some size and color code optimization remains, as well as construction of a facility to produce the taggants. Initial compatibility and survival testing has been completed for the cap-sensitive high explosives, as has pilot production of tagged explosives and activation of the tracing network. As chapter IV describes in detail, the initial testing has revealed apparent incompatibilities between the 3M taggant and one type of smokeless powder and also between the 3M taggant and one cast booster material. If and when these presumptions of incompatibility are removed, comprehensive compatibility and survivability testing and then be completed and decisions made on implementation levels before readiness is demonstrated. A similar level of testing and analysis has been accomplished for black powder while significantly less has been accomplished for smokeless powder and cast boosters. One of the key remaining technical issues is the recoverability of the taggants when pressed into large pellets (survivability has been demonstrated). Methods of approach have been explored for tagging detonators and detonating cord, but little testing has occurred.

The significant accomplishments in identification taggant compatibility testing which have so far occurred have been made possible by cooperation between the Aerospace Corp. and the explosives and gunpowder industries. Unfortunately, this working arrangement has broken down in the past few months, and the industry has, for a number of reasons, withdrawn its cooperation. The result of this change in the prior working relationship has been a significant delay in the program, particularly with regard to compatibility testing of the detection taggants. The results of these delays, together with an originally planned lag of approximately 1.5 years between the identification and detection taggant development efforts, are evident in the current status of the detection taggant development program shown in table 20.

Development of candidate detection taggants is continuing. Taggants have only recently been added to explosive materials for compatibility testing and process evaluation. As described previously, development of three candidate sensors is also continuing with laboratory-type tests showing promising results.

Projected Schedule

As a result of withdrawal of industry cooperation, technical problems which have occurred, and the uncertainty of funding for out year efforts, a firm schedule for the remaining development effort is not available. An estimate was made by Aerospace of the revised schedule for the remaining development effort; the estimate is shown in table 21. This schedule does not take into account, however, the need for additional compatibility and survivability recovery tests, particularly the resolution of the current smokeless powder and booster material reactivity issues, and the need for the evaluation of long-term effects of taggants on explosive material safety and performance. These efforts would probably add at least 1 year and possibly more to the development time. It is unlikely that the effort to demonstrate the use of identification taggants in cap-sensitive high explosives, the type of explosives with which the research effort has progressed farthest, could be completed prior to early 1981. The research on identification taggants in detonators, including pilot-plant tool-up and testing, would not likely be finished before late 1983. The research on other explosive materials would probably fall between these dates. These estimates assume a successful completion of each development stage. Technical problems may occur that add substantially to the estimate delays; continued lack of industry participation could make pilot testing impossible; even resolution of contractual problems could add months of delay.

Table 21.—Revised Schedule Estimates for the Identification Tagging Program

Program element	Aerospace preliminary estimated completion dates[a]
Identification taggants	
Color-coded taggant	Early 1981
Cap-sensitive packaged explosives	Early 1981
Black powders	
Cast boosters	Mid-1982
Detonating cord	Mid-1982
Smokeless powders	Mid-1983
Detonators	Late 1983
Detection taggants	
Microcapsule development	Mid-1982
Cap-sensitive packaged explosives	Mid-1982
Black powder	Not critical
Cast boosters	?
Smokeless powder	Late 1983
Detonating cord	Not critical
Blasting caps microcapsules	?
CECD	Mid-1982
IMS detector	Late 1981
MS detector	Mid-1982

[a] Estimated by Aerospace Corp.

SOURCE: Office of Technology Assessment.

3M has indicated that it would need a lead time of at least 22 months after receipt of a firm order before substantial quantities of taggants could be delivered. It is unlikely that a firm order would be given before resolution of all technical problems, including uncertainties regarding long-term effects. If a mid-1983 date is assumed for resolution of all identification taggant efficacy and compatibility questions, then explosives tagged with the 3M identification taggant could be in full-scale production by late 1985.

A decision could be made to implement tagging as soon as all technical uncertainties are resolved for some portion of the explosive materials, such as cap-sensitive explosives. Under these circumstances, 3M could receive firm orders by early 1981 and tagged explosives could therefore be in full-scale production as early as 1983.

The detection taggant development has lagged that of identification taggants; the development cycle may be shorter, however, due both to the learning experience of the identification taggant tests and to the fact that no survivability demonstration is necessary. The Aerospace Corp. estimates are probably quite optimistic, however, for development and test times of both the detection taggant and the detection sensors. Few compatibility tests have yet been conducted. These tests, particularly the effects of long-term storage, will take at least 2 years. No specific taggant or encapsulation method has been chosen. Pilot plant production of the taggant is likely to take a considerable time, as the manufacturing processes are complex and the reagents used quite reactive. It is unlikely that solving the technical problems and constructing proper facilities for the large-scale production of detection taggants can be accomplished in a significantly shorter period than that required for the identification taggants. Assuming completion of the compatibility tests, pilot plant testing of detection taggants in the explosive materials could be accomplished by early 1983, and assuming 22 months from that time to the availability of production quantities of detection taggents, full-scale production of explosives containing detection taggants could probably not be underway until mid-1982, with sometime in 1984 a more reasonable estimate.

As indicated previously, the estimated development schedule for the detection taggant sensors is extremely optimistic; a more realistic estimate would be that production of the sensors could be underway by late 1984.

In summary, by early 1985 it is possible that all explosives manufactured could be tagged with both identification and detection taggants, and that detection taggant sensors could be in full production. This schedule is realizable only if no major development problems occur and if taggant progress is mandated by legislation.

Implementation Philosophy

BATF has publicly stated that it feels taggants should be included only in those explosive materials that constitute a present or expected threat of use by criminal bombers. They feel that explosive materials that do not constitute a threat could be excluded. Among the materials which BATF considers appropriate for exclusion are:

1. explosives manufactured for U.S. Government agencies other than the military (e.g., National Aeronautics and Space Administration); military explosives are specifically excluded in S.333;
2. special fireworks such as used for 4th of July displays;
3. industrial tools such as explosive bolts, switches, and air bag inflators;
4. blasting agents: it is the BATF intention to tag the boosters and detonators normally used to initiate the blasting agents. The explosives industry maintains that if cap-sensitive explosives are tagged but blasting agents are not, the use of ANFO by bombers will increase, and BATF will then

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Proposed Guidelines for Exemptions to the Requirements for Tagging Explosive Materials, Bureau of Alcohol, Tobacco and Firearms, June 7, 1978.

wish to tag ANFO. See chapters I, II, and VI for a discussion of the issue; and
6. explosives which are raw materials used in a fabrication process, such as the black powder used in fuzes.

In addition to the categories eligible for exemption, certain types of explosive materials are currently exempted from regulation and are viewed by BATF as inappropriate for tagging, including:

1. explosives used in medicines;
2. fireworks sold to the public;
3. propellant-activated industrial devices, such as nail guns; and
4. fixed small arms ammunition.

Given that philosophy, the BATF/Aerospace team has concentrated on taggant research for cap-sensitive high explosives (dynamites, gels, emulsions, slurries), boosters, detonating cord, black and smokeless powders directly consumed by the public (primarily for handloading), and detonators. Blasting agents would not be directly tagged; rather the detonators and boosters normally used to initiate the blasting agents would be tagged.

A strict interpretation of S. 333, at least in the opinion of the Institute of Makers of Explosives, would not allow the Secretary of the Treasury to exempt explosives simply because they do not constitute a significant threat. Resolution of this issue may be facilitated by more specific wording in the final proposed legislation.

IDENTIFICATION TAGGANT SURVIVAL TESTING

The 3M identification taggant would have to survive the detonation of the explosive and be recoverable from the postdetonation debris to be useful in identifying the source of the explosive. It is useful to separate the survival and recovery discussions. Recovery of taggants under realistic conditions is discussed in detail in chapter III and in appendix C. Survival of the taggant is briefly reviewed here.

To assess the survivability of taggants in explosives, the tests should be carried out so that recovery is maximized. Ideally, tests would take place on a large concrete pad or in a very large bunker with deep concrete walls and floor. Unfortunately, few of the survivability tests carried out by the Aerospace Corp. were done under conditions that enhanced recovery. A majority of the tests were carried out in a 4-ft diameter steel-walled chamber. For all but the lowest power explosives, the taggants either shattered upon impact or fused plastically due to the large impact pressure pulse (estimated by Aerospace to be between 10 and 40 kilobars (kb)). Many of the other tests were carried out in a chamber with a cracked rock floor or in the open on a dirt and cinder floor. In several cases rain made the open area quite muddy or covered the taggants with a layer of water, severely decreasing the efficiency of the magnetic pickup.

The survival test results for cap-sensitive high explosives, under the varying conditions, are gathered in table 22. That table includes all the survival tests conducted by Aerospace with uniformly tagged explosives. Earlier tests in which the explosive stick was split down the center and salted are not realistic and are not discussed here. Some of the tests used unencapsulated taggants (as indicated on the table); as no difference was observed, they are lumped together in the discussion.

Aging time was another variable tested, with the material being aged up to 9 months before testing again; no effect was observed and all the tests are lumped together.

Given the diversity of test sites and conditions, it is difficult to assess each test. However, several trends appear clear:

1. Under optimum recovery conditions, using small explosive charges, many hundreds of taggants survive, even for Power Primer, the most powerful cap-sensitive

Table 22.—3M Identification Taggant Survival Testing

Explosive	Detonation pressure Kbars	Explosive weight, lb	Test site	Number of tests	Tags recovered (average)
Iregel 1 K	[illegible] 40	8	4-ft diameter steel chamber	2	900
Coalite 8S	30-40	8	4-ft diameter steel chamber	10	900
		10 (part of composite 25-lb charge)	Open air, dirt, cinder floor		150
Gelamite	25-40	2	4-ft diameter steel chamber	1	75
		8	10-ft cube concrete chamber, rock floor		4
Gel power A-2	40	8	4-ft diameter steel chamber	6	115
		8	10-ft cube concrete chamber, rock floor		10
			12x 20x 8 ft concrete bunker	3	1,450 (microencapsulated)
60% Extra	50	8	4-ft diameter steel chamber	4	160
		5 (part of composite 25-lb charge)	Open air, dirt, cinder floor		58
Tovex 800	70	10	12x 20x 8 ft concrete bunker	6	360 (microencapsulated)
40% gum gelatin	75	10	4-ft diameter steel chamber	5	8 (some tests with encapsulated, some unencapsulated)
		10	12x 20x 8 ft concrete bunker	8	543
Specially sensitized emulsion	116	8	4-ft diameter steel chamber	2	520
Power Primer	155	8	4-ft diameter steel chamber	8	11
		8	12x 20x 8 ft concrete bunker	15	318 (microencapsulated)
			4-ft diameter steel chamber	5	5
			500 x 100 ft concrete pad	6	200
		5 (part of composite 35-lb charge)	Open air, dirt, cinder floor		4
		25	Open air, muddy cinder floor		0
		25	500 x 100 ft concrete pad, dry day		25

SOURCE: Office of Technology Assessment.

commercial explosive (excluding boosters).

2. As the size of the charge increases, the percent of surviving taggants decreases sharply, particularly for the most powerful explosives. Under optimum conditions, however, dozens of taggants still survive even under rainy conditions: 28 taggants were recovered from the 25-lb Power Primer tests.
3. Confinement sharply decreases survival even under optimum recovery conditions. Only one test has been conducted with explosives confined in a pipe bomb (see chapter II discussion). In that test, a series of taggants were recovered from 60 Percent Extra Dynamite. When that result is compared to the chamber survival tests (in which over 1,000 taggants were recovered from 60 Percent Extra), it appears likely that considerably fewer taggants would survive in pipe bomb detonations using one of the more powerful explosives.

Boosters/Military Explosives

Commercial boosters are generally made from cast TNT or TNT-based explosives. These explosives have higher detonation pressures than even the most powerful cap-sensitive commercial explosives (180-200 kb v. 135 kb). Calculations by the Aerospace Corp. show that taggants will be raised above 4000 C, their decomposition temperature, by booster explosives. Testing showed fewer than two taggants recovered per pound of booster, even for tests conducted under ideal conditions on a large concrete pad. The Aerospace solution to the problem is to press the individual taggants and polyethylene into a large pellet (one-fourth inch). Tests show that approximately 45 taggants survive in a pound booster when pelletized into a one quarter-inch diameter pellet. Initial recovery tests indicate that the taggants from boosters can be recovered, but far too few tests have been completed to allow a definitive judgment.

Military explosives are generally at least as energetic as boosters, presenting even more severe survival problems for the taggants. Due to the survival issue, the expensive cost of tagging military explosives and their low frequency of use in criminal bombings, BATF does not plan to include military-only explosives in the taggant program.

Black and Smokeless Powders

Black and smokeless powders are much less energetic than the least energetic dynamite. Gunpowders are normally used as fillers for pipe bombs, however, so the effect of confinement is expected to be considerable. Tests with both black and smokeless powders were conducted in a 20-ft semicircular chamber having steel walls but a sand floor. Due to the poor recovery conditions, only 2 to 3 dozen taggants were recovered for the black powder bombs, and from 0 to 3 for the smokeless powder. When black powder bombs were detonated under near ideal recovery conditions, using the 8- x 12- x 20-ft bunker, an average of 1,155 taggants survived 1 lb of the FFFg powder. No ideal recovery tests have been conducted with smokeless powders, but the one pipe bomb test with explosives gives an indication that scores to hundreds of taggants should survive.

Detonators and Detonating Cord

Only the most rudimentary tests have been conducted of the survival of identification taggants when placed on a detonator and none conducted with detonating cord. As the taggants are placed outside of the explosive in both cases, sufficient taggants should survive to enable a positive trace to be made. How likely the taggants are to be recovered in real-world situations, however, cannot be ascertained without testing.

Summary

In summary, the 3M identification taggants survive the detonation of cap-sensitive high explosives in large numbers for small charges which are unconfined. Survival decreases as the charge size increases, but sufficient taggants should survive even a large charge of the most energetic commercial explosive. The effect of confinement significantly reduces taggant survival, but taggants can probably survive pipe bombs filled with low-energy explosives and gunpowder; their survival in pipe bombs filled with higher energy explosives is uncertain. Individual taggants do not survive booster detonation, but pellets made from the taggants do. Taggants would probably survive the explosion of detonators and detonating cord, but there is little or no test data.

Chapter IV

TAGGANT SAFETY AND COMPATIBILITY REVIEW

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Chapter IV

TAGGANT SAFETY AND COMPATIBILITY REVIEW

COMPATIBILITY OVERVIEW

The explosives and gunpowders communities operate under a particularly severe constraint. Their products must work essentially 100 percent of the time, under a wide range of user conditions. At the same time the products must remain inert, or "not" work during the manufacturing process, in storage, during transportation, and until initiated at the site of end use. Thousands of people come into contact with explosives and gunpowders every day; an accident can have extremely severe consequences to those people including injury and death. The consequences of an explosive or gunpowder not functioning when properly initiated are somewhat less severe although misfires can result in considerable safety hazard to those who must remove or work around the nonfunctioning material.

A good deal of analysis and testing is required to ensure proper operation of a particular explosive material; proper operation in this context means the material will remain reliably inert until initiated, at which point it will reliably detonate (explosives) or burn (gunpowders). Over the years qualification procedures have been developed to evaluate the reliability and safety of operation of explosive materials. These procedures vary with the organization involved, but generally combine analysis of the fundamental chemical properties of the material, appropriate testing, development of manufacturing control mechanisms, quality control of ingredients and the finished product, and long-term experience in manufacture, storage, transportation, and use. These qualification procedures are used when a new product is developed or when a significant change is made to an existing product.

The addition of identification and detection taggants to explosive materials would constitute a significant change to the material qualification program. It is therefore necessary to investigate the compatibility of the explosive materials with the taggants. This chapter briefly discusses the involved in compatibility, describes qualification procedures in industry and for defense applications, suggests the form that a qualification program should take to demonstrate the compatibility of taggants with explosives and gunpowders, and describes the compatibility testing that has been reported to date.

EXPLOSIVE MATERIALS COMPATIBILITY PARAMETERS

Explosive materials are chemical systems that liberate a large amount of energy in an extremely short time. The detailed physical and chemical behavior of these reactants is not well understood, due to the complexity of some of the reactions and the very short reaction time scale. However, the principal measurable parameters of the materials and their reactions are well known. To demonstrate compatibility of the explosive materials with the taggants, it is necessary to show that there is no significant change in these parameters as a result of the addition of taggants. The principal parameters include:

- energy density and rate of release
- sensitivity
- chemical stability

- electrical properties,
- aggravated mechanical properties, and
- toxicity.

Energy Density and Rate of Release

The energy density and rate of energy release are the two most important performance attributes of commercial explosives and gunpowder. Energy density is a fundamental chemical property of the explosive material formulation. The available energy of a given explosive material is well understood, and it can be measured with a high degree of accuracy and reliability. It can also be calculated quite accurately from the basic chemical knowledge of a particular formulation. The presence of the small amounts of taggants that are currently recommended should have only a minute effect. Limited testing has borne out this conclusion.

Generally speaking, the higher energy density explosives tend to be easier to initiate and tend to progress to a fast energy release or detonation more quickly. Primary explosives are an exception. They are easy to initiate, and build to detonation very rapidly, but do not always have a high energy density.

The rate of energy release is a function of the materials involved and the physical proximity of the fuel and oxidizer components. When the fuel and oxidizer are in the same molecule, as in nitroglycerine, the explosive can release its energy on a millionth of a second time scale. Ammonium nitrate/fuel oil mixtures, on the other hand, contain rather large, separated fuel and oxidizer components and thus release their energy on a much slower time scale. The physical proximity of the components also tends to affect sensitivity. The intimately connected materials are generally more sensitive than the grainy mixtures. The balance of fuel to oxidizer directly affects the energy density and sensitivity of the explosive material. The balance that yields idealized combustion products generally yields the highest energy and most sensitive explosives.

The rate of energy release cannot be predicted quantitatively from basic physical and chemical considerations, but it can be estimated in a qualitative way. Energy release rate can be measured accurately, but the test methods can be quite expensive and difficult. A few hundredths of a percent by weight of taggants should not affect the energy release rate.

Sensitivity

Sensitivity is an ill-defined term which has meaning in a safety sense, but is not definable with single direct physical constants. One relative sensitivity scale can be developed from impact and friction tests, another scale from electrostatic reactions, and still another from thermal considerations. All aspects of reactions to external stimuli must be considered and judged with respect to practical experience. Then, with a variety of sensitivity numbers and functional systems, a safety estimate is made — not always totally scientifically, but with an additional input from experience and common sense.

Sensitivity tests are referenced and discussed in other sections of this report, but the individual numbers are not in themselves the final criteria. It is their sum total plus experience which determines sensitivity.

Chemical Stability

Chemical stability is a critical safety parameter of paramount importance in the handling, transportation, and storage of the raw materials that go into making explosives and gunpowder and in the manufacture, handling, transportation, storage, and use of the final explosive product. The stability of the explosive products cannot be adequately predicted; one

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[illegible] R. [illegible] C. Boswell, [illegible] Tagging — [illegible] Safety and Stability [illegible] 1978, pp. [illegible]

C. Boswell, Compatibility of Identification Taggants With Explosives, Aerospace report No. ATR-78([illegible]) [illegible] August 1978.

Safety and Performance Tests for Qualification of Explosives, Kabik (NSWC/WO), [illegible] Stresau (Stresau Laboratories, Inc.), K. R. Hamilton (NWC), [illegible] (NWC), NavordOD [illegible], vol. [illegible], January [illegible] tytinely but must be confirmed by tests that demonstrate the stability behavior of the products, such as long-term rates of decomposition inherent in or between the explosive components and reaction with materials with which they are likely to come into contact during manufacture, packaging, and end use. As an example, picric acid and ammonium picrate, rather powerful high explosives, which are inexpensive and generally quite safe, were once used extensively. When these explosives come into contact with copper or copper salts, however, they become quite sensitive. Their use is, therefore, now quite limited.

Electric Properties

The sensitivity of initiation of explosives by static electricity and/or induced currents has always been a major concern. There are several modes of initiation due to electrical energy. One, inductive coupling, is serious enough to preclude the use of electric blasting caps in some operations. Direct initiation by static spark discharge is another mode. The energy of an electric field can be coupled to an explosive device in other ways, for example, by thermal heating of a wire or capacitance effects. The primaries, lead styphnate and lead azide, are extremely sensitive to electric effects. Dry nitrocellulose and black powder are also very sensitive. Most cap-sensitive high explosives and generally most blasting agents are not particularly sensitive to electric forces. Addition of taggants to the explosive mixture could cause a change in their electrical properties; buildup of a static charge during the addition of the taggant to the mix could be one mode. As analytical methods are not adequate to handle the problem, tests are routinely conducted.

Generalized Mechanical Properties

The relationship of mechanical properties to explosive safety has only recently been understood to be of paramount importance. Experience and intuition of the industry led to explosive formulations that were not ideal chemically but have proven safe and economical. Most, but not all, commercial explosives are rather soft granules, rubbery or gelatinous substances, or sometimes liquid-like.

When soft substances are subjected to impact, the mechanical forces are not concentrated in a small volume and they dissipate as low-level thermal waves. Stiff brittle materials experience strong fast compression or shock waves under impact conditions that locally produce high-energy concentrations. Local high-energy concentrations create hot spots. This means that a hot spot can be a center of intense chemical reaction and, therefore, in an explosive composition, a region of fast energy release. Thus, an initiation center is created when the rate of energy release exceeds its dissipation. Grit or hard substances can create small hot spots under loading conditions present in the mixing and packaging processes, and especially in operations such as explosive tamping in the bore hole. As an example, a small number of hard particles has been demonstrated to critically sensitize certain military explosives in United Kingdom laboratories.[1] The danger of hot spot creation may be even greater for more brittle explosives, such as those used in cast boosters.

The effects of adding taggants to explosives could be simulated using complex hydro-elastic-plastic computer codes, but the calculations would be quite expensive. In addition, lack of sufficient data on the detailed physical properties of the various materials would tend to limit the reliability of such calculations. Experimental testing must therefore be undertaken.

Toxicity

The decomposition products of explosive reactions are generally toxic; standard precautionary measures must be taken to avoid excessive exposure. The materials used in the taggants are generally not mutagenic or carcinogenic. Tests must be conducted to evaluate the toxicity of any taggant materials whose properties are not well known, and to determine if the end-product gases show additional toxicity as a result of the addition of taggants to explosive products.

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[1] E. Brown [illegible] Weapons Research Establishment [illegible] U.K., private communication [illegible], May 1979.

QUALIFICATION OF EXPLOSIVES

A new explosive compound or formulation must be subjected to an extensive series of tests before it can be qualified for use and manufacture. The number and nature of the tests differ between various manufacturers of commercial explosives and between commercial manufacturers and Government developers such as the Department of Defense (DOD) and the Department of Energy (DOE). Tests are specifically designed for the explosive product, the environment it will be subjected to, and its end use. It follows that an extensive battery of tests are required for each explosive. Interpretation of the tests, including the validity of some prescribed areas, is not straightforward and a single number derived from a test or tests cannot alone define its safety. The closest that one can come to a measure of explosive safety is the long-term accident record. It is important to realize that experience plays a role equal to good scientific understanding and execution of prudent conservative practices. The decisionmaking process as to whether or not the new explosive and process of manufacture are safe is therefore unique to each organization.

In general, the qualification procedures described in this section are those followed by agencies or companies that routinely develop new explosives or significant modifications of existing explosives, including Government agencies such as DOD and DOE and some manufacturers of commercial explosives. Companies that rarely develop new products do not generally need a comprehensive qualification program. Within those organizations that do have a comprehensive program, the complexity, qualification time, and cost vary considerably due to differing manufacturing procedures and end uses. As an example, complete qualification of a new military explosive can take several years with a total cost of many millions of dollars.

NAVORD Report OD 44811 specifies safety and performance tests for qualification of explosives for the Navy. There is also a Joint Service Safety and Performance Manual used by all three services. The DOE procedures are similar to the DOD ones but are not documented in a single manual. Each plant and laboratory has its own rules and specifications approved by the director. There are certain procedures and test methods that are common to all, however, which are briefly discussed in this section.

The initial testing is done on small quantities on a laboratory scale, usually less than a gram. Drop weight impact tests are always done, followed by friction and thermal tests such as DTA, DSC, Taliani, or others. The results of a statistically significant number of tests are then compared with known standard explosives. If the tests give satisfactory results, then a laboratory or plant level management decision, usually backed up by a safety committee review, will give a go ahead to make limited quantities sufficient to do the preliminary performance tests such as detonation velocity, detonation pressure, and shock sensitivity. These tests usually require several pounds of the new explosive to complete. At this stage more elaborate chemical compatibility and thermal stability tests are also run along with some accelerated aging tests. The small-scale laboratory tests are repeated at this stage and compared with the original results. Unless all test results are satisfactory, further work on the new explosive will be stopped.

If results are satisfactory and if the performance is as desired, then a management decision beyond the laboratory level will generally be made to proceed with limited pilot production. As much as several hundred pounds may be involved. It is at this stage that manufacturing hazards are assessed. Special tests will usually evolve at this stage that will relate to the actual manufacturing equipment such as pipe diameter in which a liquid explosive or slurry will or will not propagate a detonation. Exact details of equipment and controls are then reviewed. In the case of addition of taggants there is the possibility of gritting of the material in some part of the mixing or mechanical loading machinery. Consideration is given to fail-safe controls in the event of power losses or other equipment failures. Transportation of raw materials and finished product within the plant is planned. Barricades and remote control are planned where required. For example, the pressing of booster pellets of Tetryl or PETN is a hazardous operation and must be done by remote control and the product barricaded so that no personnel are exposed in case of an accidental explosion. Storage in magazines must also be planned.

If the new product has passed its performance and safety requirements in the pilot study, a parallel effort of evaluating the new explosive in its use environment is made. Here DOD and DOE differ significantly from industry. Military weapons are subjected to many extreme environments and the finished weapon with the new or modified explosive must undergo special safety testing to qualify it. Commercial explosives generally are used in somewhat more benign environments and the end use safety testing is more limited and less expensive. End use testing is required for permissible explosives (i.e., explosives that have been approved by the Bureau of Mines for use in underground coal mining operations). Their gap sensitivity, toxic fume production, and failure diameter must be established. For example, the minimum size bore hole required for a particular permissible explosive to function properly must be determined, as well as the safety of use in the underground coal environment (incendivity testing).

Samples from pilot production must at this stage be submitted to the Department of Transportation (DOT) for determination of shipping category. DOT has stated that addition of taggants does not change the shipping category of the explosives used in the program.

The aspects of quality control are addressed during the pilot phase of development. Chemical and physical test specifications are established to control all component raw materials. Incoming taggants must be examined for foreign material and their code verified. If the taggants are gritty, such as the Westinghouse ceramic particles, there must be assurance that each taggant is properly coated with the desensitizing polyethylene or wax. Similarly, sampling and test schemes for product quality assurance are set up at this stage.

In some cases a company's management may decide that the change involved in the new explosive is small and complete requalification is not required. The extensive experience the management has developed in the history of its plant and products makes this, in many cases, an acceptable procedure. Although taggants would be added in only a small amount by weight, their use in explosives is sufficiently different from other constituents that it is the general consensus of manufacturers and other parties that addition of taggants will require complete requalification of all tagged explosives.

Description of Qualification Tests Normally Performed

Testing of explosives involves a wide variety of tests which must ascertain chemical composition, performance, sensitivity, and stability. Chemical composition analysis is a dominating factor once it is obvious that the manufacturer and user must know what he is using and what he has made. Chemical analysis methods are not the direct concern here, as taggants change the composition little, but it is to be emphasized that knowledge of the chemical composition must be a part of qualification assessment.

Letter, F. J. Sladen (Assoc. of Amer. Railroads) to R. B. Mole (Aerospace), June 27, 1977.

There is a large number of tests that are specific to evaluation of an explosive product. The details of these tests are given in several sources. The most commonly used tests are briefly described below.

Performance

Performance is determined by measuring detonation velocity, detonation pressure, pressure rise rate, shock sensitivity, and failure diameter in explosives and ballistic properties such as burn rate, muzzle velocity, and chamber pressure in gunpowder. The addition of small amounts of inert material to an explosive probably will not affect its performance significantly; however, performance must be demonstrated. Detonation velocity measurements consist of placing electric probes in precisely measured positions, detonating the explosive, and measuring the time that it takes the detonation front to pass between the probes with high-speed electronic equipment.[8] Initiation or shock sensitivity tests are done by separating a donor explosive from the test acceptor explosive by a measured gap. The gap is varied until a 50-percent probability of explosion of the acceptor explosive is established.

Detonation pressure and pressure rise rate are measured by inserting transducers into the explosive material and recording the resultant pressures on fast response rate electronic equipment. Critical diameter testing to establish the failure diameter of an explosive material is accomplished by attempting to detonate varying diameters of the explosive. The diameter at which 50 percent of the tests propagate to a high-order detonation is the critical or failure diameter.

The chamber pressure of gunpowder is measured by the use of spherical copper crush gauges or by transducers placed in the chamber. Burn rate is measured by a variety of methods, often by placing the powder in a V groove, igniting one end, and measuring the velocity by high-speed camera, thermocouple, or pressure transducers. The muzzle velocity of the propelled projectile can be measured by a variety of methods, including photography and make or break switches.

Impact

Impact tests, although variable in nature and sometimes difficult to interpret, are critically important; their relationship to safety is obvious. They quickly provide information that categorizes the level of hazard of an explosive composition. They normally are used to tell if significant differences exist between explosive samples. Impact tests are not infallible and the results must be considered in relation to other type testing.

Impact tests range from laboratory-scale tests involving less than 35 mg to large-scale drop tests amounting to as much as 50 kg. As indicated previously, the initial tests would be laboratory-scale tests.

All laboratory impact machines are similar in principle. The energy source is a free-falling weight which impacts the explosive sample through a mechanical linkage. Criteria are established for distinguishing between positive and negative responses. The criteria differ for various laboratories so comparisons are only valid when made in a single laboratory. The tests consist of dropping the weight from varying heights onto samples of test explosives placed between them — sample weights are usually about 50 to 100 mg. The results are recorded as a go or no-go. A statistical analysis of the data determines the relative stimulus level corresponding to a chosen level of probability that the explosive will react to give a positive result according to the arbitrary criterial. Some manufacturers report a 50 percent probability height but most report a threshold height.

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[8] Safety and Performance Tests, supra.

Joint Service Safety and Performance Manual for Qualification of Explosives for Military Use (China Lake, Calif.: Naval Weapons Center, September 1972).

C. R. Walker, CARDE, Canada; E. G. Whitbread, [RD], United Kingdom; D. C. Hornig, NSWC/WO, U.S.A. The Technical Cooperation Program Manual of Sensitiveness Tests, TTCP Panel 0-2, February 1966.

[9] K. R. Hecke, C. M. Mason, and R. W. Watson, [illegible] of the Environmental Impact [illegible] Bureau of Mines [illegible] 7870, 1972.

K. W. Watson, Card Gap [illegible] Project [illegible] 8005, 1977.

Safety and Performance Tests, supra.

C. M. Mason and J. C. Aiken, Methods for Evaluating Explosives and Hazardous Materials (Pittsburgh Mining and Safety Research Center, Bureau of Mines), report No. I.C. 8541, 1972.

Bullet tests are done by firing bullets or projectiles, usually 22, 30, or 50 caliber, into the test explosive. Powder loads are varied to obtain a range of projectile velocities. The test explosive may either be essentially unconfined in an ice cream carton or highly confined in a heavy steel pipe. The minimum velocity required to obtain a reaction is reported.

Friction

In the manufacture, handling, and use of explosives there are many situations where frictional forces either are or could be present. Several test methods have been devised over the years and two of them have been used extensively in evaluating the taggants. In the Bureau of Mines tester a sample is placed on an anvil and subjected to the glancing rubbing motion of a weighted shoe attached to the end of a pendulum that swings freely over the anvil. The shoe is either mild steel or a specified phenolic resin-bonded composite. The other test, developed by commercial industries, utilizes a 2-kg torpedo which is released to slide down a V-track and obliquely impact the test sample. Both the height and angle of impact are independent variables.17

A new precision instrument developed in West Germany and known as the BAM (after the Bundesanstalt fur Materialprufung which developed it) seems to demonstrate improved discrimination. Some of the permissibles will be tested on this new machine at the Bureau of Mines. The friction surfaces in this device are ceramic. The load on the moving friction surface is varied until a response level is established.

Stability

Stability testing may be divided into two general categories. One is simply long-term storage in which samples are removed periodically and retested to see if a significant change has occurred. The second category involves accelerated aging, which generally means subjecting the test sample to extreme temperature environments and then measuring the effects of the environment. Stability tests normally conducted include the above-described friction and performance tests, plus tests which are basically thermal in nature. These thermal tests provide a measure of some physical chemistry parameters of the explosive as well as being measurements of stability.

Among the stability tests widely used are:

Differential thermal analysis (DTA) in which identical containers, one containing the sample and the other a standard reference material, are set up in identical thermal geometries with temperature sensors arranged so as to give both the temperature in each container and the difference in temperature between the containers. The data are displayed as a DTA thermogram in which this temperature difference is plotted against the temperature of the sample. Such a plot is almost a straight line if the sample has no rapidly changing thermal behavior. Excursions below or above the base line are due to endothermic (that is heat absorbing) or exothermic (that is heat releasing) reactions. The DTA analysis permits the interpretation of phase changes, decomposition and melting points. From these some kinetic information on thermal stability can be obtained. Sample sizes are in the order of 20 mg. Since the temperature of the thermal event is dependent to some extent on the heating rate, various heating rates are normally used. The standard rates are 10° C/min and 20° C/min.

Differential scanning calorimetry is very similar to DTA except the energy difference (calories) between the standard reference material and the explosive is recorded during the time-temperature program.

Vacuum stability is measured by placing a 5 mg sample in a gas burette and then evacuat-

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Safety and Performance Tests, op. cit.

[illegible] *Explosives Performance Manual*, op. cit.

R. Walker, op. cit.

R. W. [illegible]

Ibid.

[illegible] *Friction Manual*, [illegible] Bundesanstalt fur Materialprufung (BAM).

ing the burette. The flask containing the sample holder is then heated to an appropriate temperature for 20 to 48 hours. The gas evolved is measured by the manometer connected to the sample flask and then normalized to standard temperature and pressure. Test temperatures specified for military explosives are 100° C and 120° C. Dynamites and slurries are less temperature resistant and normally contain volatile compounds; therefore, the test is really only useful for candidate binder materials, gunpowders, and explosive components of detonating cord.

The *Taliani* test is almost exactly the same as the vacuum stability test except that the test is usually run in a nitrogen atmosphere at 75° C at some laboratories and 93.3° C at others; taggant tests in one laboratory were run at 120° C. At the end of 1 or 2 hours, the apparatus is vented to 1 atmosphere to eliminate the effect of the vapor pressure of water and the expansion of the original gas. The pressure change between 2 and 5 hours is measured.

In the *chemical reactivity test (CRT)* a sample of the explosive, approximately 0.25 g, is usually heated under a helium blanket at 120° C for 22 hours. Tests have been conducted at other temperatures and times; tests with the Westinghouse taggants in dynamites were run at 100° C for 4 hours. A cryogenic gas chromatography unit is then used to measure the individual volumes of the product gases including such species as nitrogen, nitric oxide, carbon monoxide and dioxide, water, and other gases as may be determined necessary. This test is used principally to determine the reactivity of explosives with other materials, i.e., a compatibility test.

In the hot *bar* test a bar is heated to 260° C and test samples of explosive are dropped on it. In the hot *ball* test a 7/8-inch square by 1/8-inch-thick piece of steel is heated to white heat by means of a Presto Lite torch and dropped on a test sample.

The *stability bath* test measures exotherm and therefore decomposition at elevated temperatures. It is similar to the DTA, but uses larger samples. The sample is generally heated to a predetermined temperature and retained there for a number of hours. Visual evidence of decomposition is sought as well as the measurement of endothermic and exothermic reactions.

The *Abel heat* test consists of heating samples in contact with methyl violet paper, usually at 71° C. The elapsed time before the paper changes color is recorded. The test is applicable only to explosives containing nitrate ester. A similar test, the *German* test, is done at 120° C and a minimum time of 40 minutes allowed before a color change.

When the stability of an explosive is being compared to the stability of that explosive after an additive (such as the taggant) has been incorporated, the tests are normally conducted with significantly increased concentration of that additive. Thus, while only 0.05 percent by weight of taggants is proposed to be added to explosives, stability tests are conducted with taggant concentration as high as 5 percent.

Incendivity Testing (The Gallery Test)

Incendivity testing is done to certify explosives and blasting accessories for use in underground mines. Permissible explosives are those that pass the prescribed incendivity test. An explosive charge, which is loaded into a steel cannon (mortar), is fired directly into the gallery chamber containing a flammable mixture of natural gas and air or natural gas, air, and coal dust. There are two large gallery tests for explosives. In one test the incendivity is measured in mixtures of coal dust and natural gas in which the gas concentration (4 percent) is below the explosive limit of the mixture. In the other, the incendivity of explosives is measured in the presence of an 8-percent natural gas-air mixture.

The gallery represents a coal mine face and is a 6-ft 4-inch diameter steel tube 80 ft long. The first 20 ft are charged with the flammable air/gas mixture and sealed by a thin membrane from the remaining 60 ft of tube, which is filled with air and acts as an expansion volume. In the 4-percent concentration test, 1.5-lb charges of the explosive are fired in the cannon under specified conditions. Ten trials are made. If any explosion occurs the explosive has failed the test. In the 5-percent concentration version, the amount of explosive that is being tested is varied from shot to shot to establish the weight required to cause a 50-percent probability of ignition.[19]

Cap Sensitivity

This test provides a simple means for differentiating an explosive from a blasting agent. A No. 8 detonator is inserted into a sample of given size and fired. If the sample is initiated to detonation, the material is classified as an explosive. A material that is not initiated to detonation is classed as a blasting agent. The test is used by the Bureau of Explosives to establish its shipping classification. The sample is put into a container at its approximate packaged density and a No. 8 detonator is inserted through the cover. The assembly is placed on soft ground in an isolated, safeguarded area, and the detonator is fired. If a crater is formed, the sample is considered to be cap sensitive. The sample container is a 1-qt spiral-wound paperboard cylinder with cover of the type used commercially for food packaging. Any commercial No. 8 blasting cap may be used as the detonator.

Spark Sensitivity

The method of determining sensitivity to spark initiation is to subject the material to single discharges from a capacitor charged to a high voltage. The maximum energy of the spark discharge to which the material can be subjected without being ignited is a criterion of its sensitivity. Results are expressed as the maximum energy in joules at 5,000 V at which the probability of an ignition is zero.[20]

Charge Generation

Taggants are electrically nonconductive. A charge can be generated on them by pouring the taggant into the mixer. A charge generation test was therefore devised by one manufacturer. The test apparatus consists of an angled chute (grounded stainless steel 2 ft long) and an ungrounded stainless steel catch container with a known capacitance connected to an electrostatic voltmeter. The taggants were poured from a polyethylene container down the chute into the catch container. The charge developed is calculated from the voltage. The relaxation time is determined by the time required for the charge to dissipate. The charge generated and relaxation time can then be compared to additives commonly added to explosive materials, such as aluminum powder.

Elements of a Taggant Compatibility Qualification Program

Taggants are sufficiently different from the materials normally used in explosives and gunpowder to require full qualification of the new taggant-explosive material combination. While the taggants are fabricated from quite inert materials and are to be added in amounts of only a few hundredths of a percent by weight, the conservative safety philosophy of the explosives industry makes requalification necessary. As the detailed physical chemistry of the explosive reactions is not completely understood, it is not possible to safely conduct a few spot tests and generalize to all explosive materials from these tests. Table 23 outlines the elements of the type of qualification test program considered adequate by the OTA study team.

In principle, the manufacture of explosive materials consists simply of adding together the fuel, oxidizer, sensitizers, and stabilizers, mixing the components, and packaging them in

Table 23.—Elements of a Suggested Compatibility Qualification Program

- Unique with each manufacturer
- Analysis to define the new explosive + ingredient
- Laboratory testing—impact, friction, thermal, chemical composition, electrical aging, chemical interaction, performance
- Plant production
- Committee and management review
- Early production and review
- Special tests
- Experience

SOURCE: Office of Technology Assessment.

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[19] [illegible]

[20] R. W. [illegible]

a casing (most explosives) or granulating the mixture (gunpowder). In practice, however, each explosive mixture of ingredients is combined and processed in ways that differ significantly for each manufacturer. The number of ingredients used can vary from 2 (for ANFO) to 15 or more for some explosives and smokeless powders. The mixing process used can vary from the simple mixing of ammonium nitrate and fuel oil to form ANFO to a complex process involving preparation of the basic ingredients (one manufacturer grinds all ingredients to a 300 mesh powder for instance) and several mixing and processing stages. The equipment used also varies widely from the wooden mixing equipment used by one manufacturer of nitroglycerine-based dynamites to the complex continuous process equipment used by one manufacturer of emulsions. End uses also vary: soft dynamites are often dropped or otherwise subjected to impact forces which would be unsafe if used with more brittle explosives such as TNT boosters. For these reasons, the qualification program must be unique to each manufacturer and must reflect the exposure expected during the manufacture, storage, transportation, handling, and use of that particular product.

While it is true that the state of the art and laboratory instrumentation of physical chemistry are not sufficiently advanced to provide a detailed understanding of the process involved in all explosive reactions, it is certainly true that a careful and thorough analysis of the probable effect of adding taggants to explosive materials can provide a great deal of information. This information can be used as a preliminary screen to eliminate obviously dangerous explosive-taggant combinations, such as taggants placed directly in primary explosives or the use of gritty taggants. In addition, the analysis can suggest critical tests and provide insight into the expected result and their interpretation. Proper analysis must therefore be considered the first element of any compatibility qualification program.

Laboratory testing must obviously play the central role in a qualification program. The exact tests to be performed are a function of the manufacturing process and end use, the results of the analysis, and the standard procedure of the manufacturers. At a minimum, tests must be conducted to demonstrate that the addition of taggants to explosive materials does not increase their impact and friction sensitivity, does not detrimentally alter the thermal, chemical, electrical, or storage properties of the materials, does not decrease stability, does not alter the chemical interactions involved (by eliminating interactions originally present or by introducing new interactions), and does not adversely affect the performance of the explosive material.

After the small-quantity laboratory tests and the analyses are successfully completed, pilot plant scale production should be initiated to investigate potential problems involved in the manufacturing, packaging, and storage of the tagged explosives and gunpowder. This testing should simulate as nearly as possible the actual manufacturing processes to be used if tagged explosives were to be produced.

Reviews, both technical and management, are an integral part of the qualification process. Substantive special reviews would probably be held at the end of the small-scale laboratory testing phase and at the end of the pilot production.

Through the qualification process the manufacturer would gain a great deal of experience in handling and working with the tagged explosives. This experience, and the general experience gained by working with the untagged explosives, and with other explosives, represent an important although qualitative part of the qualification evaluation process. For this reason, it is desirable for the manufacturers to conduct at least a large part of the qualification process. Some manufacturers do not have the adequate facilities and personnel to conduct the initial analysis and laboratory testing. This testing can be accomplished by outside agencies. It is obviously necessary for the manufacturer to participate in the pilot-scale testing phase.

In the taggant compatibility testing which has taken place (presented below), the manu facturers were asked to suggest critical tests that were required before the pilot test manufacturing and distribution program could take place. That process is not sufficient for a formal compatibility qualification program. A minimum program, such as described above, must be conducted; additional tests suggested by the manufacturer may be made a part of the program.

TAGGANT COMPATIBILITY TESTING ACCOMPLISHED TO DATE

Several hundred individual tests have been conducted in an effort to define the compatibility of identification taggants with explosive materials. These tests have generally been paired tests in which the reaction of a specific explosive material to a specific test is compared to the reaction of that material when identification taggants have been added. Materials tested include dynamite and other cap-sensitive high explosives, cast boosters, black powder, and smokeless powder.

Several varieties of identification taggants have been tested, including the current 3M baseline taggant in both encapsulated (type C) and unencapsulated (type A) form, a harder, more highly cross-linked variety of the taggant (type B), a higher melting point variety (type D), the Westinghouse ceramic taggant, and the Curie-point taggant.

No tests have shown increased explosive sensitivity due to the addition of the baseline 3M taggant (either encapsulated or unencapsulated). Similarly, no changes in shelf life or general performance or toxicity characteristics have been noted. Decreased chemical stability was noted, however, for one type of smokeless powder (Herco®).[22] Decreased stability was also noted in one type of booster material (Composition B). The tests conducted to date clearly show that some chemical reaction takes place when Herco® powder or Composition B is mixed with a high concentration of 3M taggants and then heated to a high temperature. Further research is required to determine the nature and cause of the reaction, the extent of the safety hazard created, and what remedial steps may be feasible. Extremely limited testing has indicated no significant change in detonation velocity or chamber pressure when the 3M taggants are added to smokeless powders, even at extremely high taggant concentrations.

The hard 3M taggants (types B and D) did cause significantly increased sensitivity in cap-sensitive explosives, as did the Curie-point taggant and the unencapsulated Westinghouse taggant.

Compatibility testing for the detection taggant materials has been recently initiated with black powder and cap-sensitive high explosives. No data has been formally reported, but toxicity and mutagenicity tests of the materials themselves have been negative.

The following paragraphs briefly summarize the tests so far conducted. The extent of testing described in the tables includes those whose results had been formally reported by March 1, 1980. However, OTA has reviewed all testing about which information was received, whether or not formal reports have been issued. Tests are continuing.

Dynamites

The paired compatibility tests conducted with dynamite and with EGDN are summarized in table 24. In this table and those which follow in this section, as indicated by the taggant type [illegible]. The other symbols are defined in the legend. As can be seen from the table, no significant differences in response to the various tests evaluated were ob-

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[21] [illegible] Taggant Program [illegible] Nov. 7, 1979.

[22] [illegible] D. Sexton [illegible] (OTA), "Compatibility Screening of Various Taggants With Hercules Cap [illegible] Propellants," Dec. 7, 1979.

Table 24.—Summary of Compatibility Tests Conducted With Dynamite and Dynamite Ingredients

Type of dynamite	Test type Drop weight	Friction	Sliding rod	5 kg impact	Electrostatic discharge	Heat	[illegible]	Chemical reactivity	pH
Vibrogel	AC	AC		C	C				
R[illegible] N A	AC	AC		AC	C				
Tamptite gelatin extra 60%	AC	AC		AC	C				
U[illegible]	AC	AC		AC	C				
Gel[illegible] AA	AB		X	AB	W				
60%	DWX		AB* C WXDE	CW X		CWXDE			Wx A
Nitroglycerin	C	C	A	C		A			
80/20 EGDN NG			CYZ	D		C			
40% ammonia gelatin	W			W		W			
40% ammo gelatin	W			W			W	W	
40% [illegible]				W			W		
45% hydr[illegible]				W				W	
85% gelatin	W	W	W	W					
Gelatinous permissible	W	W	W	W					
80/20 NG/EGDN		W	W						A
Power Primer		AC	Y* EA	CA CB* Y* Z*	A				

A—unencapsulated 3M taggant
B—encapsulated [illegible] 3M taggant
C—encapsulated 3M taggant
D—encapsulated higher melting point 3M taggant
E—unencapsulated higher melting point 3M taggant
W—unencapsulated Westinghouse ceramic taggant
X—unencapsulated Westinghouse ceramic taggant
Y—encapsulated Curie-pt taggant
Z—unencapsulated Savannah taggant
*including irradiated taggant
*indicates incompatibility

SOURCE: Office of Technology Assessment

served for any of the dynamite mixes to which either the encapsulated or unencapsulated baseline 3M taggants were added. Unencapsulated hard or gritty taggants of various sorts caused sensitization under impact testing.

In addition to those tests shown in the table, a small number of drop weight tests were conducted in which the 3M taggants (both baseline and the cross-linked varieties) were encapsulated in several high melting point resins. Sensitization of both Power Primer and 80/20 EGDN/NG were noted for most combinations tested.

A final series of tests examined the stability of tagged Power Primer, [illegible], and RC DN under both accelerated aging (higher temperature) and ambient aging conditions. The Power Primer showed a significant decrease in stability as measured in the Abel test after 2 months aging at 40° C. Unfortunately, no control test was conducted with untagged Power Primer, so no compatibility judgment can be made. No other signs of decreased stability appeared in the other tests.

Gels and Slurries

A smaller number of tests was conducted to compare the response of tagged and untagged gels, slurries, and emulsions. These tests are summarized in table 25. In no case tested was there an indication of changes in sensitivity or stability due to the presence of taggants. Tests were also conducted to determine if the addition of taggants to the gels and slurries would affect performance as the explosive materials aged. Tests included initiation sensitivity and detonation velocity as well as visual observation of gel quality. Both ambient and accelerated aging tests were conducted. No changes in these properties were observed. Cap sensitivity tests at low temperature were also conducted with special sensitized emulsions containing a combination of the baseline 3M and the Westinghouse taggants. The performance

Table 25.—Summary of Compatibility Tests Conducted With Gels and Slurries

Type gel or slurry	Drop weight	Skid or sled	Projectile impact	Friction	Chemical stability	Thermal stability	Tallen	Weight loss under heat	Hot tip	Hot bar	Electrostatic discharge
Gel powder A 2	A,C			A,C							C
H2O MMAN SR AN					A	C					
Mixture of [illegible] 210, [illegible] 800, [illegible] 320	C	C	C						C	C	
Gel [illegible]	C			C			C	C			C
Gel-powder	C			C			C	C			C
Permissible (unspecified)	W	W		W							

A—unencapsulated 3M taggant
B—unencapsulated hard-core tested 3M taggant
C—encapsulated 3M taggant
D—encapsulated higher melting point 3M taggant
E—unencapsulated higher melting point 3M taggant
W—[illegible]
X—unencapsulated Westinghouse ceramic taggant
Y—encapsulated [illegible] taggant
Z—unencapsulated [illegible] point taggant and [illegible] taggant
MMAN—monomethylammonium nitrate
SR—sodium nitrate
AN—ammonium nitrate

SOURCE: Office of Technology Assessment

of the tagged explosives was superior to the untagged control samples. It should be noted that the reason for any change in performance should be carefully investigated.

Cast Boosters

The tests comparing the sensitivity and stability of tagged and untagged cast boosters are summarized in table 26. The 3M taggant did not affect the sensitivity of any of the cast boosters explosives in any of the paired testing. Evidence of decreased stability was observed in tests conducted at molten booster material to which 3M taggant had been added. In a series of tests, Gnex heated booster explosives to temperatures between 120° and 165° C for a period of 16 hours. Evidence of decomposition of the explosives occurred, including bubbling, discoloration, and the appearance of voids. Pentolite (50/50 PETN/TNT), Octol (25/75 TNT/HMX), and an explosive mixture similar to Composition B were tested. The only paired test was with the Composition B-like material. Composition B normally contains just under 60 percent TNT and just under 40 percent RDX, with the rest being wax. The Gnex mixture used A-3 instead of pure RDX. As A-3 contains approximately 4 percent wax, the composition of the Gnex Composition B differs from standard Composition B. Ignoring the nomenclature difference, the tagged composition B showed significantly more severe degradation at the 120° C test temperature than did the untagged composition B at a 130° C test temperature. As no control tests were conducted with an untagged batch of explosives for the Octol and Pentolite tests, it is impossible to ascertain if the taggants were responsible for the observed reactions. While testing is often conducted at temperatures above those encountered in normal use, it is extremely dangerous to heat common booster materials to temperatures above 120° C. The test serves as an indication of a potential compatibility problem. More carefully controlled tests are currently underway at the Naval Surface Weapons Center, White Oak, Md. Preliminary indications are that a 50/50 mixture of unencapsulated taggants and TNT undergoes a chemical reaction at 120° C; research is continuing to determine the nature, cause, and safety significance of this apparent incompatibility.

On July 18, 1979, an explosion and fire occurred at the Gnex factory in Camden, Ark., causing damage which Gnex has estimated at $2 million. The explosion took place in a melt pour operation in which scrap high explosives were being melted. Gnex now asserts that the scrap materials available for melting down included some materials containing 3M identification taggants. Gnex further asserts that the explosion began in a way that resembled the

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[1] Letter [illegible] Wilkinson (Gnex [illegible]) [illegible] Davis [illegible] Aerospace [illegible] Stanford Engineering [illegible] Aerospace [illegible] Order [illegible] 0/1979

Table 26.—Summary of Compatibility Tests Conducted With Cast Boosters

Type of booster	Test type Drop weight	Vacuum stability	BAM friction	Pendulum friction	Sliding rod	Thermal stability
PETN	A, B, C, X, W		A, B, X	a	C, W	
Pentolite	A, B, X^a	A, C, Y, Z	A, B, X		a	
50/50 pentolite	a			a	a	
Composition B	a			a	a	c
TNT	a			a	a	
RDX	a			a	a	

A—unencapsulated 3M taggant
B—unencapsulated hard core [illegible] 3M taggant
C—encapsulated 3M taggant
D—encapsulated higher melting point 3M taggant
E—unencapsulated higher melting point 3M taggant
W—unencapsulated Westinghouse [illegible]
X—unencapsulated Westinghouse ceramic taggant
Y—encapsulated Curie-point taggant
Z—unencapsulated Curie-point taggant
a[illegible] taggant
cIndicated incompatibility

SOURCE: Office of Technology Assessment

reaction of tagged booster material in the above tests, Goex claims that the explosion must have been caused by the taggants. The Aerospace Corp. asserts that no tagged booster material was located at the Camden factory at this time, and that furthermore the low concentrations which Goex asserts were present could not have initiated an explosion; the tests to which Goex refers involved extremely high taggant concentrations. OTA is not familiar with the facts regarding the possible presence of taggants, and is not aware as the report goes to press of any experimental data on the possible desensitizing effects of low concentrations of taggants mixed with TNT/RDX mixtures.

As would be expected, the more gritty taggants clearly showed evidence of sensitizing the booster explosives. In the case of the Curie point taggant, sensitization occurred even for encapsulated taggants; these are the only tests showing sensitization with encapsulated taggants.

Black Powder

The black powder compatibility test results are summarized in table 27. Neither the black powder nor the black powder tailings are sensitive to either the friction or impact tests conducted, even for the gritty taggants. However, no stability tests were conducted.

Table 27.—Summary of Compatibility Tests Conducted With Black Powder

Type of powder	Test type Drop weight	BAM friction
FFFg	A, B, X	A, B, X
Tailings	A, B, X	A, B, X

A—unencapsulated 3M taggant
B—unencapsulated hard core-polished 3M taggant
X—unencapsulated Westinghouse ceramic taggant

SOURCE: Office of Technology Assessment

Smokeless Powders

The compatibility tests conducted with smokeless powders are summarized in table 28. Only the encapsulated 3M taggant (type C) was tested. Tests were originally conducted by Hercules, Olin, and Du Pont on their own smokeless powders.[55] No evidence of sensitization or change in electrostatic properties was observed. In the case of the Herco® powder, however, the Taliani and German heat tests both indicated a significant decrease in stability due to the addition of the taggants (in a 50-percent concentration) to the smokeless powder. (Although Hercules tested only Herco® powder, Hercules believes that their

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[55] [illegible]

Table 28.—Summary of Compatibility Tests Conducted With Smokeless Powders

	Test type									
Type of powder	Impact	Friction	Electro-static discharge	Impinge-ment	Critical height to explosion	DSC	Teflon	Vacuum test	Ballistic velocity	Ballistic pressure
Hercules HPC								c		
Hercules Bullseye								c		
Hercules Herco®	C	c	c	c	I	c	c	I		
Du Pont Hi-Skor	c	c	c					c	c	c
Du Pont PB	c	c	c					c	c	c
Du Pont IMR 301	c	c	c					c	c	I
Du Pont IMR 4064	c	c	c					c		
Olin 231								c		
Olin 296								c		
Olin 452								c		
Olin 540								c		
Olin 473								c		
Olin 571								c		
Olin 680								c		
Olin 748								c		
Olin 760								c		
Olin 785								c		
Olin WC 571									c	c

C=compatible with taggant
I=indicated incompatibility

SOURCE: Office of Technology Assessment.

other brands of powder designed for the reloading market are so similar to Herco® that similar test results could be expected. OTA believes that this is highly likely for the four other Hercules brands that are chemically identical to Herco®. It may not be the case for the three Hercules brands with different compositions.) As no changes were noted for the Du Pont or Olin Abel tests, the Herco® tests were repeated at the Naval Ordnance Station, Indian Head, Md. The decreased stability was confirmed. A more carefully controlled series of tests was then conducted by the Lawrence Livermore Laboratory (LLL) for the Aerospace Corp. in an attempt to isolate the element or elements of the taggant materials which are responsible for the incompatibility.[1] Briefly, the tests indicated that there exists an incompatibility between something in the Herco® and the melamine/alkyd which forms the basic matrix of the 3M taggants. It may be a basic reaction with the melamine alkyd or with the catalyst used to speed up the cure time. There may also be reactions occuring between the taggant pigments and the Herco® powder. The LLL tests are continuing in an attempt to resolve the issue.

At the present time, there appears to be an incompatibility between the 3M taggants and the Herco® smokeless powder. Hercules has indicated that it does not consider the combination safe and has stopped all work on it. OTA feels that, on the basis of the tests just described, the conclusion must be drawn that the 3M taggants cannot be safely added to the Herco® powder unless the present incompatibility is resolved. Some publication exists questioning the validity of tests using severely increased concentrations of the taggant materials (50 percent in the tests v. 0.05 percent of encapsulated material in the proposed taggant program), but it has not been demonstrated that there is a threshold concentration below which the problem disappears, and that such a threshold would never be exceeded in practice.

Preliminary ballistic tests have been conducted on tagged WC 571 shotgun powder manufactured by Olin. Ballistic velocity, chamber pressure, and time to initiate burning were measured. Tests were conducted at three temperatures (–30° C, 20° C, and 50° C) and four taggant concentrations (2, 4, 10, and 20 times the recommended concentrations), both with the taggants mixed in the powder and with the taggants separated and placed directly over the primer flash hole.

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[1] [illegible]

The OTA rationale for such extreme test conditions (up to 20 times the nominal concentration, 100-percent segregation) was an attempt to evaluate the worst-worst case conditions that might appear due to segregation of the taggants from the powder during manufacture, transportation, and storage.

No deviation from acceptable ballistic performance was noted for the ambient and high temperature tests. A steady decrease in velocity and pressure was noted with increasing taggant concentration. The practical significance of this depends on the extent to which taggant concentration would vary in actual use by handloaders, which can and should be established by careful testing and statistical analysis. At the low temperature condition two anomalous test results occurred. Evidence of improper ignition occurred in 1 of the 20 firings at the 20 times normal concentration 100 percent segregation condition. Improper ignition would constitute a safety hazard as the round might not clear the barrel. Significantly reduced ballistic performance occurred on 1 of the 20 tests at 4 times nominal taggant concentration with the taggants and powder mixed. No other performance degradation was noted, even under conditions of higher taggant concentration.

DISCUSSION OF COMPATIBILITY TEST RESULTS

Several hundred tests have been conducted to investigate the compatibility of explosive materials with identification taggants. Most of the tests have been conducted with the baseline 3M taggants and variations of these taggants; a large number of tests, however, have also been conducted with several other candidate taggant materials. Compatibility tests have included those designed to indicate increased sensitivity, decreased stability, changed chemical properties, and changed performance. Explosive materials have included dynamites, gels, emulsions and slurries, cast boosters, black powder, and smokeless powders. A full set of qualification tests has not been completed on any single explosive product and only a small fraction of the hundreds of products has had any testing. Given these limitations, it is still possible to draw some tentative conclusions on the compatibility of taggants with explosive materials (which may change as more data becomes available) and to discuss the implications of these results for the taggant program.

First, it is important to realize the purpose of a compatibility qualification testing program. In brief, a set of tests is established on the basis of analyses, the projected manufacturing, storage, transportation, and end-use processing of the material, and the normal procedures and experience of the organization conducting the tests. If the candidate explosive product fails to pass any of the outlined tests in the series, it is judged to have failed the qualification test program. If a flaw can then be remedied, then the tests can continue, but the material must pass all of the critical tests, not just a majority or a certain fraction.

There is no indication that the 3M taggants are incompatible with dynamites, gels and slurries, or black powder.

Composition A booster material and Herco smokeless powder do show significantly reduced stability in the presence of the 3M identification taggants. Furthermore, careful testing appears to indicate that the incompatibility is with the basic melamine alkyd material of the taggants, rather than with a particular pigment or the polyethylene encapsulate. Tests, similar to those conducted with Herco, were conducted with other smokeless powders; no loss in stability was noted for other Hercules powders, or for the Olin or Du Pont smokeless powders. The reaction therefore probably is between the melamine alkyd and one of the sensitizers or stabilizers of the Herco®. As the formulations of both Herco® and the 3M identification taggants currently stand, the two are not compatible. Further investigation may isolate the element of incompatibility and it may be possible to replace elements in either the Hercofina or the taggants to remove the incompatibility. It is not yet possible to tell whether the booster material incompatibility is with the basic taggant material or with one of the components of the taggants.

Both the smokeless powder and booster material tests took place at high temperatures, and in most of the tests at high taggant concentrations. The temperature used for the smokeless powder test was higher than would be expected in actual manufacturing, storage or use; the temperature used for the cast booster is sometimes reached in manufacturing processes. In each test a taggant concentration of 10 percent was used rather than the 0.05 percent tagging concentration suggested for routine use. The tests, nonetheless, indicate that the stability of the materials has decreased due to the addition of taggants, and that a reaction is taking place between elements of the taggants and elements of the explosive material. Standard qualification test procedures require that such evidence be considered a sign of an existing incompatibility between the materials. Carefully controlled testing and extensive analysis must be completed before it can be determined if the observed evidence of incompatibility does, in fact, indicate a potential safety problem during the manufacture, storage, transportation, and use of the tested materials. Unless demonstrated otherwise, it must be assumed that it is unsafe to add the taggants to that smokeless powder or the booster material. Until the elements of the incompatibility have been identified, a question remains as to the safety of adding the taggants to other smokeless powders and booster materials, although tests with other smokeless powders and boosters have shown no evidence of incompatibility.

The significance of the Olin ballistic property tests cannot be fully assessed at this time. The Olin tests indicated that increasing taggant concentrations lead to a reduction in velocity and pressure, and this could create a problem if and only if it proves impossible to mix taggants with smokeless powder in such a way as to avoid extreme variations in taggant concentration from one round to the next. Testing is required to establish how great a variation in concentration could be expected using reasonable manufacturing methods, and normal transportation, storage, and loading procedures. The Olin tests did show one case of poor performance (at four times the suggested taggant concentration), but performance anomalies sometimes occur without taggants, and a single anomaly is not enough to justify a prediction as to whether taggants would increase the frequency of such occurrences. The segregation tests were conducted with 100 percent segregation, which appears quite unrealistic. Testing is needed to establish the extent of segregation which might occur before a realistic worst case can be defined. Unlike the Hercofina Composition B cases, the Olin ballistic property tests do not appear to OTA to constitute sufficient evidence to require presumption of an incompatibility. It remains true, however, that no presumption of compatibility can be made until adequate ballistics tests have been conducted.

This raises the question of the value of a taggant program from which smokeless powders and cast boosters were excluded. As noted in chapter VI, smokeless powders are used in a significant percentage of criminal bombings (approximately 20 percent) and cause 10 to 20 percent of deaths and injuries. As also noted in chapter VI, criminal bombers are likely to react to a taggant program. If smokeless powders are not tagged, then a logical reaction would be for a large number of bombers to switch to the use of smokeless powders. Although bombs using smokeless powder are considerably less efficient (lower specific energy) than those using cap-sensitive high explosives, smokeless powder bombs are responsible for a considerable number of injuries and deaths. Effective controls over smokeless powder by means other than taggants may be possible but appear unlikely. Booster material is rarely used as a criminal filler. It is used, however, to initiate blasting agents. The current BATF plan would be to not directly tag blast ing agents. But to tag the boosters and detonators used to initiate the blasting agent. Exclusion of boosters from the taggant program may well require an alternate control mechanism for blasting agents. Given the extremely large quantity of blasting agent produced (3.4 billion lb annually), any other control mechanism may have serious cost consequences.

The above discussion concerned the results of the tests to investigate the compatibility of the baseline 3M taggants with explosive materials. Tests were also conducted using hard or gritty taggants. In all cases the unencapsulated hard taggants caused increased sensitivity to the drop weights, and in most cases, to the sliding rod tests. The ceramic Curie point taggants caused increased sensitivity in some cases even when encapsulated, although no incompatibility was noted for the Westinghouse or hard core 3M taggants when encapsulated with polyethylene. When a hard resin was used as an encapsulant, the 3M taggants showed a clear sensitization of PETN. The implications of these tests are obvious. Hard or gritty taggants must be encapsulated. The encapsulated material should not only be soft but it should also be a heat sink. The use of a soft additive is a common desensitizer in military explosives. Composition B and other RDX-based explosives include approximately 1 percent wax with a softening point in the 800 F range.

The tests show that encapsulated gritty taggants, such as the Westinghouse ceramic taggant, may be alternatives to the baseline 3M taggant. As even a small amount of the unencapsulated material (0.01 percent) causes increased sensitivity, however, great care must be exercised to ensure essentially 100-percent encapsulation. This may seem to create an impossibly high quality control problem. However, the problem may not be as difficult as it first appears. If 99 percent of the taggants are encapsulated, then unencapsulated taggants would constitute only 0.0025 percent by weight of the explosive, almost two orders of magnitude less than the amount demonstrated to cause increased sensitivity. Tests of these extremely low levels might well show no increased sensitivity.

As noted above, much compatibility testing remains to be accomplished. Identification taggants have undergone comprehensive testing with a representative sample of dynamites, gels, slurries, cast booster materials, smokeless powders, and black powder, even after the resolution of the compatibility questions which testing so far has revealed. It would eventually be necessary to test taggants with all such materials before instituting a comprehensive tagging program. In the case of detonators and detonating cord, compatibility testing has not been completed even with a representative sample. Compatibility testing of detection taggants started only recently, and with the exception of testing with detonators it is even less advanced than compatibility testing of identification taggants.

It is necessary to resolve the incompatibility observed between the 3M identification taggants and the Composition B booster material as well as the Hercules® powder, however. Before it makes any sense to finish the rest of the tests with other materials. The resolution of the smokeless powder incompatibility could take any of several forms, including:

- Reformulation of the 3M taggant—this would require starting essentially from scratch in the taggant testing program, as the reformulated taggant would undoubtedly exhibit different compatibility as well as survivability properties.
- It might be possible to develop a different taggant that proved compatible with smokeless powders, and to use the existing 3M taggant for explosive materials with which it is compatible.
- Reformulation of the Hercules® powder—this may or may not be easily accomplished, once the element or elements that react with the taggant are isolated. This option would only be viable if no other smokeless powders were found to be incompatible.
- Exclusion of Hercules from the taggant program—the economic effects on competition would need to be carefully considered, as would alternate control mechanisms.

- Exclusion of smokeless powders from the identification taggant program — such an exclusion would rely on the fact that smokeless powders would be less effective than cap-sensitive high explosives and that the detonators would be tagged. OTA believes that this last approach may not be viable—too many people are currently killed or injured using smokeless powders and the numbers would almost certainly increase if that approach were adopted. Alternate control mechanisms for smokeless powders would be required.
- Demonstration that the observed stability problem does not constitute a safety hazard. The observed decrement stability occurs at elevated temperatures and at more than two orders of magnitude higher taggant concentration. As the decomposition rate is both temperature and concentration sensitive, it may be that no safety hazard exists under realistic conditions. If it could be positively demonstrated that the decomposition rate was within the normally accepted range for temperature regimes and concentrations which reflect worst-case actual use conditions, then it *may* be possible to add taggants to the smokeless powder, particularly if no further incompatibilities surface. However, demonstration of safety would have to be quite convincing to overcome the currently perceived incompatibility.

A resolution of the booster incompatibility problem could be accomplished by a similar set of methods, once the elements of its incompatibility have been identified.

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TAGGANT COST REVIEW

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TAGGANT COST REVIEW

OVERVIEW

A detailed review of the potential cost and economic impacts of the proposed taggant program was conducted in parallel with the safety and utility segments of the study. In this analysis, the assumption was made that the taggants work and are safe to put in explosive materials. It was furthermore assumed that the current incompatibilities observed between the 3M identification taggant and one type of smokeless powder, as well as one type of cast booster material, would be resolved in a way which has no additional cost impact. The various cost elements were estimated by:

- **drawing on existing studies and testimony, and**
- **interviewing the identification taggant manufacturer, explosive and gunpowder manufacturers and distributors, users of explosive materials, law enforcement personnel, and sensor instrumentation engineers.**

Other important economic issues were addressed in parallel with the development of the program cost. The addition of taggants to explosives has a potential cost impact to an industry in which explosive type decisions are frequently made on an economic rather than performance or brand loyalty basis. An additional taggant material cost issue is that raised by the probable monopoly of supply by one company, particularly by 3M for the identification taggants. The question of assuring price and taggant availability also required attention. Introduction of taggants into the explosive fabrication process will cause changes in the manufacturing process due both to possible mixing costs and to the other costs associated with purchasing, controlling, and using the taggants. Other one-time costs are associated with product requalification tests for safety, potential costs for waste disposal equipment, and added plant capacity to make up for lost productivity.

Identification taggants require additional recordkeeping by the manufacturer, by wholesalers and distributors, and by the retail stores. There are law enforcement costs associated with the recovery and tracing of identification taggants from explosions and with the subsequent tracing process. These costs must, however, be compared with the cost of current law enforcement practices.

Detection taggants require a sensor and a system to sample and convey the air from the sample room to the sensor. The sensor and sampling system requires operation and maintenance, although it is possible that current security personnel could operate the additional equipment at an airport, for instance. There is an additional potential cost associated with possible delays raised by false alarms in the detection system. Significant false alarms could cause enough ill-will (in addition to high costs) to lead to the abandonment of automated usage of detectors in situations such as airports.

A final cost aspect which must be considered is the economic effect of a taggant program in which only selected explosives are required to be tagged. In the cost-conscious commercial explosive industry, that could eliminate certain products or companies from the marketplace, perhaps resulting in significant local unemployment.

Due to the fact that the identification taggants have progressed further down the development path, the relative precision of the cost estimates associated with their introduction into explosives is expected to be greater than the estimates of detection taggant and related sensor costs. The precision of each estimate is indicated during the course of the cost analysis discussion.

This cost analysis by OTA has been an intensive short-duration study. Of necessity the study was accomplished by drawing on existing studies from a wide variety of sources and by a limited number of onsite interviews with industry and Government. Discussion with industry included various explosives manufacturers and 3M, the taggant manufacturer. Various user types such as mining companies (underground and surface), construction firms, and quarry operators were also visited. Extensive discussions were also held with the Aerospace Corp. (the taggant program development contractor), with the Institute for Defense Analyses, with Management Science Associates, and with consumer groups such as the National Rifle Association and the National Muzzle Loaders Association. Government agencies with whom detailed discussions were held include the Bureau of Alcohol, Tobacco and Firearms (BATF), the Federal Aviation Administration (FAA), the Department of Commerce (DOC), the Bureau of Mines (BOM), and various Department of Defense agencies.

Various degrees of uncertainty exist in costing out the taggant program, as little field data exists and some potential manufacturing process applications are undefined. Table 29 illustrates the qualifications of the estimating basis for the taggant program, indicating the status of pilot testing and the OTA understanding of the manufacturing processes required to implement taggants. On the right side of table 29 is set forth, in generic terms, the method for estimating utilized, such as direct estimating, Aerospace Corp. analyses and assumptions, the Institute of Makers of Explosives (IME) member estimated inputs, Sporting Arms and Ammunition Manufacturers Institute (SAAMI) estimated inputs, etc. The particular methods and data sources utilized are documented throughout the study where appropriate.

Table 29.—Qualification of the Estimating Basis for Taggants

Type explosive	Pilot tested	Taggant only process understood	Estimating basis Process alter	Process tooling	Other capital expenses
Cap-sensitive packaged explosives	Yes	Yes	Direct estimate Proprietary data as made available IME member inputs	Direct estimate	Direct estimate Nonrecurring Requalification of products
Cast boosters	Yes	Yes	Aerospace analysis/assumptions		Waste disposal: additional waste due to "unacceptable" contaminated tag batches
Smokeless powder	Underway	Yes	Aerospace analyses SAAMI estimate	Equipment required: storage bins, hoppers, equipment for weighing, packaging, transferring tag samples	
Black powder	Yes	Yes	Case Study: storing • security • administrative & records • mfg. process cleanup		Investment affect losses in productivity
Detonating cord	Planned	No	Aerospace assumptions	Testing: Design required (no effective equipment currently available)	Cost of taggant inventory including the cost of money
Blasting caps	Planned	No	Aerospace assumptions	Significant cost expected—new machine must be designed	

Aerospace estimates utilized and OTA survey inputs.

SOURCE: Office of Technology Assessment.

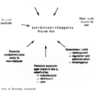
The primary methodology utilized in the cost analysis was to translate all program costs, both nonrecurring one-time costs and recurring costs, to annualized values. Capital investment costs were annualized over a 10-year period at an interest rate of 10 percent. This method was utilized for all initial expenditures (requalification, waste facilities, etc.) with the exception of testing costs estimated for detonators and blasting caps, which were written off in a 5-year period at 10-percent interest.

The taggant program costs vary substantially as a function of the level of implementation of the program. In this study an OTA-identified baseline program was assumed for baseline cost estimates, and the parametric variation of the costs examined as a function of higher and lower level implementation plans. Cost estimates were also generated for the implementation program proposed by BATF.

All cost data and program estimates in this report are stated in fiscal year 1979 dollars to assure consistent treatment. A list of taggant program cost elements was developed to permit a comprehensive framework for treating all potential costs and resources impacted by the taggants program. Figure 10 illustrates the general sources of costs potentially involved in the program, while a detailed list of potential cost elements is shown in table 30.

For purposes of exposition throughout this cost impact assessment, a baseline set of conditions or assumptions is utilized in the determination of a total program estimate. These are shown in table 31. The baseline program

Figure 10.—Schematic Illustration of General Cost Element Sources


Direct Costs added by manufacturer
Markup costs added by distributor
Taggant materials
Direct costs incurred by user
Identification Taggants Program Cost
Potential productivity loss costs to manufacturer
Potential economic cost impacts due to application:
— manufacturer
— distributor
— user
Government costs
— development
— regulation and administration
— investigatory

SOURCE: Office of Technology Assessment

Table 30.—List of Taggant Program Cost Elements

Taggant materials
Identification taggants
Detection taggants

Detection sensor-related costs
Sensors
Sensor sampling and transport instrumentation
Operations and maintenance
Cost of false alarms

Explosive and gunpowder manufacturing costs
Nonrecurring costs
- Tooling
- Storage
- Product requalification safety testing
- Waste disposal facilities
- New investment to offset production losses

Recurring costs
- Materials-handling process labor
- Record keeping
- Quality control
- Production losses
- Waste product loss
- Inventory costs
- Administration expense

Markup

Distributor costs
Record keeping
Storage
Markup

User costs

Other costs
Government administration
Taggant program development
Investigative costs

SOURCE: Office of Technology Assessment.

Table 31.—Baseline Taggant Program Configuration

Encapsulated identification taggants
- Explosive weight or units to be tagged and tagging concentration

Category	Quantity		Concentration
Cap-sensitive packaged explosives	325,000,000	lb	.05%
Boosters	5,000,000	lb	1 %
Black powder	400,000	lb	.05%
Smokeless powder	5,000,000	lb	.05%
Detonating cord	800,000,000	ft	5 mg/ft
Blasting caps	[illegible]	units	50 mg

Identification and detection taggants
,000 sensors to be deployed
- Sensor mix: [illegible]
10% taggant contamination permitted
- "Composite tag" permits rework of previously tagged material
- [illegible] production of each [illegible] explosive (date-shift basis)
- New taggant code for each

SOURCE: Office of Technology Assessment.

includes several provisions which, OTA believes, would do much to hold down costs without a significant reduction in the utility of the program: blasting agents are not tagged; the identification taggant code is changed only when the date, shift, or product changes (resulting in some code numbers corresponding to a large batch size and others to a small batch size); and a special composite code is used for taggants added to already tagged material (permitting rework without removal of previous tags). The special composite code taggant would be added to material with more than 10 percent cross-contamination; such a taggant would indicate that the material used was a composite and that taggant codes other than the specific composite code should be ignored.

Although confidence levels are relatively high for certain elements of costs, particularly for the identification taggant program, other program elements are subject to considerable uncertainty (particularly the number and types of sensors to be employed in the detection taggant program). Attention is called to the baseline assumptions associated with each cost element throughout the discussion of cost.

In the following section the costs of the taggant materials are developed. This is followed by detection taggant sensor-related program cost estimates. The potential cost increases occurring during the explosive manufacturing process and at the distribution level are then estimated. The potential cost impact(s) to the users of explosives are subsequently discussed. Other cost impacts, including the cost contribution by Government for administration, investigation, and taggant program development are set forth in the next section. A general synthesis and summary of the taggant program cost estimates follows, with the relative precision or accuracy of the estimates discussed after that, including aspects of cost uncertainty and program cost sensitivity. The adequacy of the current cost data and suggested further research are briefly discussed in the last two sections, respectively.

TAGGANT MATERIAL COSTS

The cost of both the identification and detection taggant material is heavily influenced by the amount of explosive material to be tagged, the form of the tagging material, and the concentration levels. Material cost estimates are developed for the baseline program described above.

Identification Taggants

The annual quantity of explosives produced in the United States, shown in table 32, was estimated based on data obtained from IME, BATF, Aerospace Corp., BOM, and DOC. An unresolved problem exists with respect to the production of cap-sensitive packaged high explosives. The basic difficulty stems from the method of reporting data in the surveys collected by both BOM and DOC. Some "unknown" quantity (both permissible and other high explosives) of cap-sensitive explosives is reported as included in unprocessed ammonium nitrate and "all other purpose" categories in order to avoid disclosing individual company data. Since the data are masked to protect the marketing positions of explosive manufacturers, the uncertainty in annual quantity will persist. For purposes of this study, the quantity of 325 million lb/year (as adopted by Aerospace) will be used as the baseline condition.

A second variation concerns the level of black powder produced. Approximately 2.5 million lb of black powder are produced per year in the United States, but the majority is used as a raw material in other fabrication processes, such as fuzes. Approximately 400,000 lb are sold directly to the consumer; this amount is included in the explosive materials to be tagged. Table 32 shows the production quantity, the concentration of unencapsulated taggant material suggested by the BATF/Aerospace team, and the resultant quantity of unencapsulated taggants required annually.

Price estimates, obtained from 3M as a function of annual taggant production, are shown in figure 11. The estimates quoted are for unencapsulated taggants produced in 5-lb lots and assume a firm order for a minimum of 2 years. The 150,000-lb level is a result of a detailed costing study conducted under contract to the Aerospace Corp. The target price and worst case estimates for the 75,000- and 100,000-lb levels were provided by 3M in response to an OTA request. The range of prices reflects the fact that less time was available for the 3M estimates than the original 150,000-lb level, resulting in some uncertainties. These target prices have all been through a rigorous price review within the 3M corporate structure and represent the firmest commitment possible short of a production contract.

Table 32.—Annual Taggant Requirements

Explosive category	Quantity to be tagged	Concentration level (percent by weight)	Annual taggant production (lb of unencapsulated taggants)
Cap-sensitive packaged high explosives	325,000,000 lb	0.025%	81,250
Cast boosters	2,000,000 lb	0.05%	1,000
Smokeless powder	5,000,000 lb	0.025%	1,250
Black powder	400,000 lb	0.025%	100
Fuse/detonating cord	500,000,000 ft	5 tags/in	160
Blasting caps	84,000,000 caps	50 mg each	6,920
			90,320

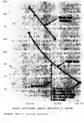
SOURCE: Office of Technology Assessment.

Assuming linear extrapolation between the data points, the price for unencapsulated identification taggant material was estimated by OTA (from figure 11) to be approximately $93/lb for the estimated 90,000 lb of taggants to be required annually. This cost figure assumes production in 10,000-lb lots. In cases where most lots are substantially smaller, taggant costs per pound of explosives might rise.

This figure is for unencapsulated taggants, while the baseline OTA program assumes the taggants are encapsulated in an opaque polyethylene wax. The 3M technical people furnished an estimate of the cost of encapsulating the taggants in polyethylene wax but were unable to estimate the cost impact of using an opaque polyethylene wax. Based on the above data, OTA estimated that it would cost $55/lb

Figure 11.—3M Identification Taggant Cost Estimates

- 5-lb tag lots
- Unencapsulated
- 2-year minimum required



SOURCE: Office of Technology Assessment

for opaque encapsulated taggants, as the baseline tagging level is 0.05 percent by weight of *encapsulated* taggants, and the encapsulating material weighs the same as the unencapsulated taggants. ($83 for 1 lb of unencapsulated taggants, plus $17 for 1 lb of encapsulating material plus the process, equal $110 for 2 lb of encapsulated taggants or $55/lb.) This corresponds to 2.75 cents/lb of cap-sensitive explosives in the identification tagging materials.

3M and a number of other individuals and organizations have based their cost estimates on a price of $200/lb of encapsulated taggants and an additional library maintenance fee of $100/year per unique taggant species. This identification taggant cost has been clearly identified by 3M as the cost of taggants produced in their current pilot plant, which is labor intensive. If there is no program legislated to tag commercial explosives, it does not represent a potential cost figure if the taggant program is expanded. Details of the cost of taggants, as a function of total quantity needed, were given above. No additional fee would be required for library maintenance.

Detection Taggants Materials Costs

The Aerospace Corp., as part of its taggant contract effort for BATF, has put considerable effort into the development of molecules for detection taggant purposes. As a result of investigation of the properties of several hundred potential molecules, five chemicals are currently considered excellent candidates for the program. These perfluorinated cycloalkanes are:

- PDCB — perfluorodimethyl cyclobutane,
- PMCH — perfluoromethyl cyclohexane,
- PDCH — perfluorodimethyl cyclohexane,
- PFD — perfluorodecalin, and
- PHSP — perfluorohexyl sulfur-pentafluoride.

The final selection of a particular detection taggant will depend on the results of compatibility testing, efficacy in conjunction with the detection taggant sensor, price, and availability.

The microencapsulated detection taggant would be directly incorporated as a free-flowing powder in commercial explosives and gunpowder. Since part of the chemical selection criteria include a low or negligible utilization of these materials in standard manufacturing (to minimize false alarms due to ambient or background), standard cost/price data currently available was supplemented by requests by the Aerospace Corp. to a number of companies for budgetary pricing-type estimates at quantity levels of 200,000 lb/year. A range of estimates was received for both the cost of the de tection taggants and for the encapsulation process. Taking these values into account, as well as adjustments for process yield, the following range of estimates was made by OTA:

Lower end of range	$22.25/lb
Medium	40.00/lb
Higher end of range	58.75/lb

For purposes of the baseline study OTA has utilized the medium cost of $40/lb of encapsulated detection taggant. The Aerospace Corp., in their preliminary impact study, estimated conservatively a value of $63/lb, based on early data. With the more recent inputs it is reasonable to estimate a lower value for detection taggant material. Uncertainty as to the value chosen remains due to the following factors:

- final taggant selection,
- final contract price,
- cost of encapsulation,
- the weight efficiency of the encapsulation process, and
- the final yield ratio of the encapsulation process.

Since the detection taggant program remains in the early stages of development, uncertainty will persist in this value. Variations from this value will be examined in the cost sensitivity analysis. The relative significance of the variations of the detection taggant's cost is not expected to greatly perturb the overall taggant program cost estimates.

Cost and Supply Guarantees

The identification taggants currently proposed to be used are manufactured only by 3M and are a proprietary product manufactured by a proprietary process. In addition, a significant public overhead cost would have been incurred before the compatibility of explosive materials with the taggants could have been demonstrated. Mandating the addition of identification taggants to explosive materials would therefore ensure a monopoly of the Government-mandated market for 3M at least for a period of several years. Under such circumstances, development of a mechanism to regulate the virtual monopoly of the identification taggant market that 3M would enjoy is highly desirable. While several suppliers are capable of supplying the vapor detection taggant production in the necessary quantity will probably require significant capital investment, much of which would be amortized by the taggant program. It is therefore desirable to have a mechanism that will ensure the price of the vapor taggant material as well.

A number of mechanisms are available to regulate the price of taggants, including:

- a price level set by Congress in the enabling legislation,
- regulation as a public utility,
- licensing by 3M of competitors,
- a multiyear, fixed-price contract, and
- a free-market price regulated only by the probability of competition or sanctions if prices get too high.

The free-market mechanism is probably unacceptable, given the long time needed to either develop and qualify an alternative taggant or enact sanction legislation. Legislation of a price or use of a regulation mechanism similar to that used for public utilities would be an awkward, time-consuming process for a product whose total annual value would be on the order of $11 million.

Licensing is not only disagreeable to 3M, but it is probably not cost effective. The cost of the taggant material includes a component for amortization of the taggant production facility, as a new facility must be built and the primary market for identification taggants would likely be the mandated explosives market. The process that 3M plans to implement is capital-intensive. Licensing of other manufacturers would therefore require the construction of facilities for the licensees in addition to a new 3M facility, resulting in a substantially higher total cost.

A long-term contract may be the most effective mechanism. In fact, the 3M cost estimates are conditioned on firm orders for a 2-year period, although 3M is willing to consider contracting periods of up to 5 years. The details of the contracting mechanism have not been addressed by this study, although there may be some advantage in a single contracting agency (presumably within the Government) rather than separate contracts with each manufacturer of explosives and gunpowder. In addition to saving the cost of multiple contracting, the single contract concept would limit the amount of information available to 3M on numbers of product lines and production quantities of explosives, a matter of some sensitivity to the explosives manufacturers.

Assurance of availability of a taggant supply is a related issue. A number of approaches are possible, including:

1. manufacture and maintain a large inventory of taggant materials either by the manufacturers directly or by the Government acting as purchasing agent; a 6-month supply should certainly be adequate;
2. develop redundancy by constructing a backup manufacturing site for taggants, and
3. utilize the discretionary power of BATF to provide relief from the legislation in cases of emergency induced interruption of supply.

A detailed tradeoff would be necessary to decide the relative merits of options 1 and 2. Option 2 shares the cost impact of additional capital-intensive construction identified for the licensing option considered above. The acceptability of option 1 to the explosives and gunpowder manufacturers may be heavily weighted by who bears the cost burden of maintaining the 6-month inventory. Option 3 carries with it the possibility of weakening the utility of the taggant program, and would probably be implemented only if necessary, for instance, if a manufacturer ran out of taggants and would otherwise be forced to stop production.

In the OTA baseline costing estimate, the 6-month inventory option was assumed, and manufacturing cost estimates include the cost of the taggant inventory as well as the cost of money to carry the inventory.

SENSOR-RELATED COSTS

The detection taggant sensor program is in the very early stages of development. To date, most of the effort in the detection area has been devoted to the vapor taggant selection process. Because detection taggants are still in an early development phase, a relatively high degree of uncertainty exists in several of the principal cost-driving factors. The sensor(s) development and production unit cost estimates are one area, and the quantity of sensors to be deployed is another. Table 33 sets forth the major qualifications which underlie cost estimates of the sensor program. Three systems are currently undergoing development by the Aerospace Corp.: the continuous electron capture device (CECD), the ion mobility spectrometer (IMS), and the mass spectrometer (MS). Performance specifications are severe for each of these candidate options including sensitivity at the parts-per-trillion level and low (0.01 percent) false alarm rates. Parts lists for each of these systems have been identified and priced by Aerospace Corp. instrumentation engineers and scientists. Commercial engineering "rules-of-thumb" have been utilized in estimating production price levels. Development cost budgets and outyear forecasts totaling on the order of $2.5 million have been estimated for advanced engineering development. The estimates, by the very nature of a development program, assume that development proceeds smoothly and without major redirection of design activity. In addition to the total number of sensors likely to be deployed, uncertainty exists in:

- the development cost,
- the production unit cost,

Table 33.—Qualification of Estimating Basis for Sensors

	Continuous electron capture device	Ion mobility spectrometer	Mass spectrometer
General availability of technology	Currently utilized in lab situation—Brookhaven Breadboard	Commercially available 6 years—50 currently in use	High-cost laboratory model in use—no commercially available that meets cost and performance requirements
Taggant program status	Design of field instrument in progress	Off-the-shelf PC-100 instrument is being characterized for candidate taggants	Preliminary design underway for low-cost field unit
Facts (materials) identified and estimated by Aerospace	Yes	Yes	Yes
Taggant sensor production cost estimated with engineering rule-of-thumb factor applied to material costs	Yes	Yes	Yes
Quantities to be implemented in a national program	Quantities depend on scenario selection—also decisions in purchase; instruments made with a large and varied mix: community—airports, courthouses, nuclear reactors, nuclear weapon centers, military communication centers, national shrines, Government office buildings, etc.—quantities are uncertain and open-ended		

SOURCE: Office of Technology Assessment

- the system or systems actually employed and
- the relative mix of systems to be deployed if several successful candidates emerge.

Numbers of Sensors Needed

Estimates of the total quantity of sensors likely to be deployed in the field are further subject to a wide range of uncertainty, as the decisions must be made individually by a large number of organizations, although regulatory and other agencies such as FAA and the Nuclear Regulatory Commission could potentially represent customers for large numbers of sensors. The target to be protected must be high-valued and subject to controlled access. With the exception of checked baggage, it is unlikely that any location that does not now have a guard would employ a detection taggant sensor. Likely targets for bombers, and likely locations for sensors, include airports, nuclear reactors, nuclear weapons centers, military communications centers, Government buildings, and computer centers. There are approximately 620 airports in the United States using approximately 400 X-ray machines to scan carry-on luggage. There are 70 nuclear power stations and thousands of Government buildings of one type or another. Police bomb squads may also use portable units for investigation of bomb threats.

In the baseline program identified by OTA, a total of 1,500 sensors was assumed deployed. That number would include one sensor each for passenger screening, carry-on baggage, and checked luggage for each current X-ray machine station, as well as 300 for protection of other high-value targets. The low-level program assumed 900 sensors, 2 each for each current X-ray station. The high-level program assumed 5,000 sensors, enough for all controlled-access transportation facilities, nuclear power plants, important Government buildings, and portable police use.

Sensor System Related Costs

The annual unit system cost for the sensors, including installation, maintenance, and false alarms, is shown in table 34. Since each point of controlled access where detection sensors are contemplated is already manned by personnel (who check entering personnel or search baggage), direct operator costs are not included for the baseline case. Excess false alarm rates would possibly be a cause for adding personnel. Training would be accomplished by the detector instrumentation company and occur either at the company as part of an operator training seminar or at the time of equipment installation. Maintenance costs for all of the candidate systems are estimated at 10 percent of the hardware investment cost.

Table 34.—Vapor Taggant Detector System Cost (annual cost per unit)

Hardware investment	Continuous electron capture device	Ion mobility spectrometer	Mass spectrometer
Cost per unit	$12,355	$15,100	$36,370
Installation and checkout	500	500	500
Hardware subtotal	12,855	15,600	36,870
Annual cost of investment per unit	2,082	2,537	6,795
Annual maintenance	1,236	1,510	1,430
Cost of false alarm @ .05% rate	0	0	0
Total annual cost per detector	$3,318	$4,050	$8,225

a Includes cost of training operating personnel.
b [illegible]

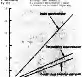
SOURCE: Office of Technology Assessment

Figure 12.—General Functional Network for Vapor Taggant Detector

Total Cost = A + B + C + D

SOURCE: Office of Technology Assessment

Figure 13.—Estimated Annual Vapor Taggant Detector Cost v. Quantity Deployed



Mix of Sensors

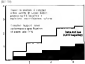
Development of the CECD, IMS, and MS sensors is expected to continue in parallel fashion. A system type would be selected and demonstrated to be feasible. A mix of possible sensors in the field is likely (given feasibility demonstration) since each instrument type would be found to offer advantages in given scenarios for performance (specificity, threshold, etc.) and costs (acquisition and operation and maintenance). The baseline program assumes a total of 1,500 sensors is deployed: 90 percent MS and 10-percent MS.

The annual cost per sensor for this mix is approximately $4,580. In the final synthesis section program costs have been estimated for various levels of implementation of sensor system to fit various utility levels examined in this study.

False Alarm Costs

False alarm response costs have been examined by FAA as a function of the false alarm rate for various technical approaches including explosive vapor detector schemes. The FAA study examined two airline operations at Logan Airport, Boston, as a basis for the operational scenario. As false alarm rates increase, so do the number of hand searches required and, therefore, the cost of operation. The results of that analysis, adjusted for the taggant vapor sensor, are shown in figure 14, where estimated annual cost impact for each of the airlines is shown as a function of the vapor detector false alarm rate. Incremental costs are incurred in a stepwise fashion at alarm rates greater than 0.05 percent (1 in 2,000). Since the performance design specification for the taggant sensor false alarm rate has been established at 0.01 percent (1 in 10,000), no false alarm costs are expected if this performance goal is realized. Cost level impacts reflect the particular operational activity characteristics of Logan Airport and would not necessarily reflect nationwide characteristics. Discussions with FAA personnel indicate that nationwide cost effects due to false alarms would be less than that reflected for the Logan scenario. Costs of false alarms, on a national average, would probably not be significant at rates as high as a few percent, the current false alarm rate for airport magnetometers.

Figure 14.—Estimated Cost of False Alarms v. False-Alarm Rate



SOURCE: Office of Technology Assessment.

The cost of false alarms can also be calculated as a function of the cost per bag checked. At a rate between 0.05 and 0.175, the estimated cost of increased inspections due to false alarms is approximately 2.5 cents/bag at Logan Airport. At an annual level of 300 million checked bags per year in the United States, the estimated cost of false alarms due to checked baggage alone would be approximately $8.4 million. As noted, the cost estimate for Logan is considered high for purposes of estimating national levels; nonetheless, the potential cost due to false alarms would be a significant cost impact when considered in absolute terms. Since the cost of security checks at airports are ultimately passed on to the airline customer, the direct per capita costs would be minimal. At an average of 1.5 bags checked per passenger, the per capita annual cost for the above conditions would be on the order of 5 cents. A high false alarm rate could lead to delays in the departure of aircraft with significant losses to both airlines and the delayed passengers.

EXPLOSIVES AND GUNPOWDER MANUFACTURING COSTS

The value-added costs of the taggant program that occur at the explosive manufacturing level are addressed here. As has been alluded to earlier, the manufacturing process implications for tagging implementation are best understood for cap-sensitive packaged high explosives where pilot-plant tests have been accomplished. The tagging implications for detonating cord and detonators, conversely, are only addressable in a general way. As no testible designs have been set forth for the required testing, and engineering design and analysis have not been accomplished, the implications for existing cap design remain uncertain. Because the OTA study effort was time constrained, the major survey emphasis was placed in the area of cap-sensitive packaged high explosives. The estimates for cap-sensitive manufacturing costs are based on discussions with the major manufacturers. Some of these estimates are applied to other explosive types where appropriate. Preliminary estimates and analysis by the Aerospace Corp. are also utilized as a cost basis for certain explosive types and associated cost elements where deemed appropriate. These cases will be cited and commented on as to their reasonableness and depth of treatment.

The following subsections address each of the manufacturing cost elements considered in this study. The last subsection summarizes the estimates of the various elements of manufacturing cost.

Estimates of the current cost for each of the explosive product categories considered are shown in table 35 along with the raw material costs. The difference between price and raw material costs is made up primarily of labor, overhead, and markup (profit). Specific data for these important elements of cost were not available to this study since this kind of data is considered extremely proprietary. The uncertainty in the specific division of the other costs and markups makes it difficult to assess the degree to which the explosives manufacturer will either absorb or pass on through higher markups, the added cost of taggants in the manufacturing process. This issue will be amplified later.

Table 35—Current Manufacturing Cost/Price Data

Explosive product category	Current cost of explosive raw materials	Average current price per unit
Cap-sensitive explosives	8¢/lb	30¢/lb
Cast boosters	50¢/lb	$1.50/lb
Black powder	[illegible]¢/lb	$6–$8/lb
Smokeless powder	NA	$5–$8/lb
Detonating cord	2¢/ft	5¢/ft
Blasting caps	20¢–30¢/cap	90¢/cap

Source: [illegible]

Aerospace Corp.

[illegible]

[illegible]

SOURCE: Office of Technology Assessment.

Revised Processes, Tooling, and Facility Costs

Cap-Sensitive Packaged Explosives

Requirements for additional tooling and equipment to accommodate the tagging process of dynamites, emulsions, slurries, and gels consist of equipment for weighing, handling, means of transferring taggant samples, and storage bins for secured storage areas. The cost to equipment to add the taggants into the explosive mixing process is small, as most manufacturers use a batch mixing operation. Based on data provided by the explosives manufacturers, OTA estimated the added cost for these investments as a function of the unique batch size and other considerations regarding waste and productivity. OTA assumed a 10-year life, 10-percent interest rate in order to annualize this initial investment. Detailed requirements for other manufacturers of cap-sensitive packaged explosives were not made available to this study. OTA believes that these tooling cost requirements are representative of the cap-sensitive explosives industry.

The Aerospace Corp. indicated that some manufacturers might wish to install automatic taggant-dispensing equipment, and concluded that this cost should be similar to the cost of the labor it replaces and hence would be covered under the labor cost element. OTA's study survey and site visits did not uncover any particular requirement for automatic dispensing equipment of either gel or dynamite manufacturing facilities.

Cast Boosters, Smokeless Powder, and Black Powder

Specific tooling and equipment requirements for these product categories were not available. For estimating purposes the assumption was made that the estimate for cap-sensitive explosives should be a representative value until detailed requirements are established.

Detonating Cord

Tooling designs must be developed in order to provide tagging capability at each detonating cord production line. Aerospace Corp. indicates that several pieces of hardware have been tested but no effective equipment is currently available. They further feel that a station configuration would apply both the identification and detection taggants together with an adhesive before the final assembly polyethylene sheath is applied, and that a reasonable cost for a station having a 5-year life is $50,000. Five such stations would be required by the industry for an annual production of 500 million ft. The estimated cost for detonating cord tooling is $250,000. Amortizing this cost over 5 years at 10-percent interest yields an annual cost of $66,000 or $0.00013/ft.

Blasting Caps

The process by which taggants would be added to blasting caps has not yet been determined. It may well vary from one manufacturer to another. Alternate possible approaches are to place the taggants between two end plugs, embed the taggants within a single end plug, or add taggants to an existing interior polyethylene strip. Cost will vary considerably depending on the process chosen and the current cap assembly process. For purposes of this study, a conservative value of $2 million per manufacturer was assumed. Amortizing the $8 million cost (four manufacturers) over 5 years yields an annual cost of $2,112,000 or $0.025/cap. This figure would be high if one of the simpler methods of tagging detonators were adopted. However, the effect on the total cost of a tagging program is small.

Labor

Cap-Sensitive Packaged Explosives

Manpower estimates by the manufacturers indicated a range of requirements varying from two to six additional men at a site. The variation results from differences among particular site layouts, processes, and procedures in use. For instance, in one company effort would be required in various locations such as the dope house, works control laboratory (including works chemistry), and in the magazine area. Additional activities involved include ordering, stocking, weighing, and supplying taggants to operators; collecting data, taggant samples; keeping records of codes; handling increased record keeping in magazine areas; and examining the codes before use in the manufacturing process. One contractor also indicated increased manpower costs due to code confusions and returned shipments. It should be noted that incremental labor costs for the actual mixing operation of taggants and related packaging are essentially zero. All additional estimated labor costs are associated with peripheral activities in coordinating, handling, and recordkeeping activities.

The estimate for labor, as estimated by the manufacturers, is slightly greater than 1 cent/lb of explosives, which reflects approximately five to six additional men at the plants.

Cast Boosters

For the purposes of developing a baseline estimate, the Aerospace Corp. analysis is utilized here. Assuming that this will be a manual process, two additional personnel were estimated per assembly line. Given the four manufacturers (eight lines) the estimated annual cost is $480,000 or $0.057/lb of explosive.

Black Powder

Labor costs associated with tagging black powder were studied by the Goex Co. and referenced in the Aerospace Corp. *Inflationary Cost Impact Study*. The estimated cost per pound of black powder for manufacturing labor of 1.5 cents is based on replacing the present date-shift code with a tagging material system. Elements include:

- storing tagging materials,
- security for storage and handling of tagging materials,
- administrative and recordkeeping, and
- impact on the manufacturing process (assuming a cleanup would be required in

the plaza and packhouse operation each shift).

The cost is exclusive of taggant material costs. Based on the study by Gnex, OTA estimated the cost of labor for black powder to be 1.5 cents/lb.

Smokeless Powder

The Aerospace Corp. estimated labor effort added cost per pound of smokeless powder to be on the order of 6.6 cents (including the distribution system costs) and assumed that much of the cost could be absorbed within the current manufacturing and distribution organization. The estimate is based on the following assumptions:

- 2,000 lb/lot
- 2,500 different lots produced/unit
- 100,000 cases/year (50-lb cases)

Manufacturing costs were estimated to be 0.4 cents (of the total 6.6 cents). Since adequate data are unavailable to validate this estimate, OTA estimated the cost of manufacturing labor for smokeless powders at the same level as black powder using the Gnex estimate of 1.5 cents/lb.

Detonating Cord and Blasting Caps

The Aerospace Corp. estimate for detonating cord assumes that each assembly line would require one additional person to man a tagging station and to operate it during production. At $25,000 per man the five stations would add an annual cost of $125,000 or $0.00025/ft of cord.

Similarly the Aerospace Corp. estimates are used for blasting caps. Several additional workers may be necessary to operate and maintain the new equipment required. A reasonable estimate is four per manufacturer (there are four manufacturers) for an annual increase of $400,000. The resulting cost per blasting cap is $0.0048/cap.

Productivity

Cap-Sensitive Packaged Explosives

Potential productivity losses have been estimated by the industry to be as high as 15 percent. The primary cause of such losses would be halting production to change taggant codes and avoid contamination. Consequently, the extent of such losses depends on the degree of taggant cross-contamination that would be permissible and the taggant batch size. Various kinds of cost can impact the situation. They are:

- loss associated with scraping of hoppers,
- new investment to offset production losses,
- loss of the market for mixed scrap currently sold as an inexpensive explosive, and
- new investment for expanding waste disposal facilities.

As currently perceived by one major manufacturer of cap-sensitive packaged high explosives, productivity losses will have a direct cost impact in each of the areas noted above. Productivity losses are estimated at 15 percent in the condition where cross-contamination is not permitted and on the order of 7 percent where batch cross-contamination of 10 percent is permitted. Waste losses associated with scraping of hoppers every fourth mix were also estimated. A significant amount of the mixed scrap material is currently marketed as a low-quality explosive. If this material could no longer be marketed due to extensive taggant cross-contamination, there would be a further loss in profits. Current environmental regulations require that waste be disposed of by means other than burning in the open, in effect requiring additional waste disposal facilities. In order to maintain the current production and sales base and thus maintain an adequate profit level for the company, additional production facility augmentation would be required to offset the expected losses in productivity.

The total cost due to losses in productivity could thus add up to several cents per pound of explosives for the worst case condition. If a 10-percent taggant cross-contamination level were permitted (BATF assumes this level), the cost impact would drop dramatically. If a special "composite code" were created, then tags containing this code could be added to scrap material and any other material containing cross-contamination in excess of 10 percent. Investigators finding tags with the composite code would know that any other tags should be ignored. This would essentially eliminate costs for decreased productivity. The OTA baseline program assumes that such a composite code taggant is used so that productivity losses are negligible.

Other Explosive Categories

Since plant testing of adding taggant materials to boosters, gunpowder, detonating cord, and caps has not taken place, the effects on productivity are not apparent. For purposes of costing the baseline system, OTA assumed there would be no productivity losses.

Inventory Costs

Inventory costs, including the associated cost of money, are a function of supply held in inventory. There is no reason to assume the tagged finished product would be held longer than is currently the case. It may be necessary, however, to stockpile a significant inventory of the taggant material to ensure an uninterrupted supply, particularly for identification taggants, where there is likely to be only one supplier. For the baseline case, the quite conservative assumption was made that a 6-month inventory of both types of taggant materials would be stockpiled. The added costs for the various types of explosives would be:

Cap-sensitive	$0.0021/lb
Boosters	$0.0087/lb
Smokeless powder	$0.0021/lb
Black powder	$0.0021/lb

Space and added labor have been included in the facility and labor costs detailed above. For the baseline case, no additional storage or labor would be required for cap-sensitive explosives, as the batch size would be the same as the current date-shift batch size. For the high-level program with 10,000-lb maximum batch size, each batch would need to be separated by an access aisle from other batches, requiring additional space and labor. Access aisles would need to be maintained for inventory control and inspection.

Quality Control

Quality control cost estimates are included in the total cost element. Some level of effort is required to ensure the taggant code and taggant quality prior to mixing. This effort would take place in the plant lab or "works" lab to examine each code before use in the product. This appears to be a reasonable precaution since the integrity of all substances entering the "mix" must be assured to maintain prior safety levels. In addition, occasional specimens would be examined to assure that the taggant mixing specification (uniformity, shelf life, etc.) was being achieved.

Safety

Requalifying all product lines with taggant materials would be a necessary safety testing requirement for the various explosives manufacturers. This one-time capital cost would involve analysis and testing of each type of product. To an extent uncertain at this time, the pilot testing programs have and will contribute to the requalification effort. Due to the uncertainty involved, OTA included the cost of safety requalification in the cost element estimates. It should be pointed out that the absolute cost levels of nonrecurring costs are not insignificant. However, after amortizing these costs over the significant production weights of explosives produced annually, the relative contribution of incremental costs to a pound of explosives is quite small.

Recordkeeping Costs

In order to maintain the integrity of the identification taggant tracing network, a certain amount of additional or new recordkeeping must take place within the explosives distribution network. Current Federal requirements are that each explosive package and shipping case be marked with an identification code citing the:

- plant of manufacture,
- the date and shift manufactured, and
- the type and grade of explosives.

Explosives covered under this regulation are the:

- cap-sensitive packaged explosives (dynamites, slurries, water gels, and emulsions),
- cast boosters,
- blasting caps,
- black powder, and
- detonating cord.

Records of the identification code must be maintained at the manufacturer level as well as each subsequent distributor. Smokeless powders are currently exempt from this requirement, although powders used to handload pistol ammunition must be recorded at the retail sales level.

The cost of recordkeeping has been included as part of the labor manufacturing cost elements.

Markup

To the extent that incremental tagged costs are passed on to distributors and users, markup costs must be included as part of the final product price. No specific data were available to identify markup for most of the explosive product categories. For purposes of establishing a baseline cost estimate, OTA assumed a 10-percent markup at the manufacturing level. This value may seem low, but all handling costs have been specifically covered in other cost elements, including an overhead allowance. Markup in that sense is essentially profit on the additional costs. Normal markups must cover all of the handling costs.

In addition to manufacturing level markups, OTA considered the pyramid of markups that occurs throughout the various echelons of distributor and retailer levels. This is addressed in the next section.

Summary of Manufacturing Costs Added

Manufacturing costs elements and total cost added as a result of the inclusion of identification and detection taggant materials in explosives are summarized in table 36. The added

Table 36.—Summary of Explosives and Gunpowder Manufacturing Costs Included

Cost element	Baseline case cap sensitive	Boosters	Black powder	Smokeless powder	Detonating cord	Blasting caps
Nonrecurring costs						
Training	Yes	Yes	Yes	Yes	Yes	Yes
Startup	No	No	No	No	No	No
Product requalification	Yes	Yes	Yes	Yes	NA	NA
Waste disposal facilities	No	No	No	No	No	No
New investment to offset product losses	No	No	No	No	No	No
Recurring costs						
Manufacturing process labor						
Recordkeeping	Yes	Yes	Yes	Yes	Yes	Yes
Quality control						
Product losses	No	No	No	No	No	No
Waste product loss	No	No	No	No	No	No
Inventory costs	Yes	Yes	Yes	Yes	Yes	Yes
Administrative expenses						
Total added cost per unit of explosives	0.3¢/lb	2.7¢/lb	2¢/lb	7.2¢/lb	(4¢/ft)	5.1¢/cap

[a] Not available.
[b] Included in labor.

SOURCE: Office of Technology Assessment.

costs include the estimated costs to the manufacturer and associated markup as well as the markup placed on the cost of the taggant raw materials.

Manufacturing costs for cap-sensitive packaged high explosives are based on detailed inputs received from a major manufacturer. The raw data are proprietary information and are not shown here. The detailed cost data were analyzed and alternative ground rules were established to gain insight into cost effects where taggant batch size was varied. Related effects were taken into account regarding the productivity and waste issues. The cost elements included in various assumptions, along with the bottom line cost per pound of explosives, are shown in table 37.

Table 37.—Cost Summary of Cap-Sensitive Packaged High Explosives Manufacturing Cost Variations With Assumptions

	Costs included				
	Case 1	Case 2	Case 3	Case 4	Case 5
Cost elements	4000-8000-lb batch size	20,000-lb batch size	20,000-lb batch size plus other cost-containment [illegible]	[illegible] batch size [illegible] during production	Plant [illegible]
Site management	Yes	Yes (less than case 1)	Yes (less than case 1)	No	No
Production losses	Yes	Yes	Yes	No	No
Waste	Yes	Yes (less than case 1)	No	No	No
Registration	Yes	Yes	Yes	Yes	Yes
Waste disposal facilities	Yes	Yes (less than case 1)	No	No	No
Equipment and storage	Yes	Yes (less than case 1)	Yes (less than case 2)	Yes (less than case 3)	Yes (less than case 3)
Investment to offset production losses	Yes	Yes (less than case 1)	Yes (less than case 2)	No	No
Taggant inventory costs	Yes	Yes	Yes	Yes	Yes
Administration	Yes	Yes	Yes	Yes	No
Bottom line cost per pound of explosives excluding markup	4.0¢/lb	2.8¢/lb	[illegible]¢/lb	0.8¢/lb	0.5¢/lb

SOURCE: Office of Technology Assessment.

DISTRIBUTOR COSTS

A general schematic illustration of the distribution network for explosives is shown in figure 15 while the network for gunpowder is shown in figure 16. Detailed quantitative networks are not available; however, these illustrations serve to depict the manner in which transactions take place within the industry. Within the networks, potential cost impacts occur in the areas of recordkeeping, packaging and handling, storage, and further potential pyramiding of markup costs throughout the distribution network.

Recordkeeping at Distribution Levels

Recordkeeping and control of packaged high explosives are required by the present date-shift code regulation. Additional partitioning of explosive products may be required beyond that required by the date-shift code regulations, which may or may not have an incremental cost effect at the distribution level. No detailed studies of additional recordkeeping elements which would be required, or the time necessary, have been conducted to date. The assessment of new activity requirements by the distributor includes:

- comparing the taggant lot numbers with the bill of lading with greater frequency,
- identifying each explosive product by type [illegible] by type and taggant lot number to facilitate locating records,
- expanding storage space for the increased number of books and records, and
- increasing the time to locate the proper product and taggant lot number at each

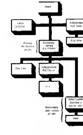
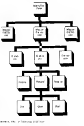

Plant
Large customer
Independent distributor
Customer
Primary distribution points
Company owned distributor
Customer
Independent distributor
User
Small outlet (hardware store, etc.)
Secondary distribution points
User

Figure 16.—Schematic Distribution Network of Gunpowders



SOURCE: Office of Technology Assessment

(due to the greater number of records that must be searched)

The Aerospace Corp. further considered:

- segregating material on trucks and in magazines in a smaller quantity and recording additional information in orders, invoices, and inventory lists.

An analysis by the Aerospace Corp. of available BATF tracing records revealed that recordkeeping entries on bills of lading would involve:

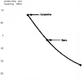
- 1.25 entries per order (20,000-lb tagging level) (based on 282 BATF traces of seven manufacturers in 1978 and 1979)
- 1.48 entries per order (12,000-lb tagging level) (based on Du Pont data) and 1.66 entries per order (7,900-lb tagging level) (based on dynamite traces)

In effect these data indicate that the additional recordkeeping, processing, and handling efforts for the finished explosives may be increased by up to 66 percent depending on the tagging level. A plot of activity increases versus tagging level is plotted in figure 17. This plot underscores the dramatic inverse relationship of recordkeeping activity with the unique tagging batch level.

The Aerospace Corp. further reviewed the additional data entry requirements which

Figure 17.—Recordkeeping Activity v. Tagging Level

- Cap-sensitive packaged explosives
- Impact on distributor/retailer
- Based on Aerospace analysis of BATF tracing record



SOURCE: Office of Technology Assessment.

would be required on the sale. Tagged explosive materials would require approximately 25 percent more entries than the untagged explosives for transactions at the distributor level. The analysis was specifically for tagging at the 20,000-lb level. At the retailer explosive user level an 8.7 percent increase in data entries were computed using Federal form 4710 and the bill of sale or delivery ticket.

Aerospace did not quantify the absolute cost impact as a result of this tracing analysis, but did conclude, however, that the costs would be insignificant for cap-sensitive packaged high explosives. The OTA analysis assumed that negligible added costs exist at the distributor retailer level for

- cap-sensitive explosives,
- boosters,
- detonating cord, and
- blasting caps.

This conclusion is particularly appropriate for the baseline case in which the taggant batch corresponds to the current date-shift code batch size.

The impact on the distributors of black and smokeless powders is somewhat different. Black powder and pistol-grade smokeless powder currently have significant recordkeeping requirements, while the other smokeless powder grades have no current recordkeeping requirements. (Pyrodex, a black powder substitute, would be marketed and regulated like smokeless powder so incremental recordkeeping costs would approximate those of smokeless powder.) An estimate was therefore made of the additional cost of entering the currently unregistered smokeless powder in, and deleting it out of, the records of each distributor level by taggant code. It was assumed that a record for an item would take 2 minutes. The further conservative assumption was made that the average size of an item at the master distributor level was 25 lb (primarily case lots handled), was 10 lb at the distributor level and was 2 lb at the retail level. Since considerable recordkeeping requirements currently exist for pistol-grade smokeless powder, the costs were assumed to be half those of the other powders. A small additional cost for recordkeeping was assumed at the retail level for black powder. The costs per pound added by these costs are shown in table 38.

Storage

Explosives are now generally separated by date-shift code batches for magazine storage at all levels in the distribution chain, as records must be kept and physical control maintained by date-shift batch. For the baseline taggant case, no changes would be necessary. If the taggant batch were smaller, then additional storage space would be required for access. An estimate was made of the cost of magazine space, based on two data points. The added

Table 38.—Estimated Cost Impact for Powders of Distribution Network (cents per pound)a

		Smokeless powder	
Distribution level	Black powder	Retail loading grade	Rifle and shotgun grade
Master distributor			
Recordkeeping	c	3b	3.40
Storage	0.2	0.2	0.2
Distributor/wholesaler level			
Recordkeeping	c	5d	6e
Storage	0.2	0.2	0.2
Retail level			
Recordkeeping	1	5e	30f
Storage	0	0	0
	1.4	15.1	38.8
Total cost through the distribution chain			
Black	—	—	1.45
Powder			13.65
Other	—		38.88

a If pistol powder is assumed to be 95 percent of total smokeless powder the average cost impact for smokeless powder is 28¢/lb.

b Determined by integrated powder distributor analysis ratios
c Based on [illegible]
d Assumed 2 [illegible]
e Assumed [illegible]
f Assumed [illegible]
SOURCE: Office of Technology Assessment.

cost per pound of explosives was less than 0.1 cents, even for the case in which 10,000 lb maximum lots were tagged. For black and smokeless powders, the assumption was made that separation by taggant lot would require additional storage space at both the master distributor and distributor levels, but probably not at the retailer level. Using the same data base as above the cost was estimated to be approximately 0.2 cent/lb at each level as shown in table 38.

Summary Cost Including Markup

Distribution level costs are summarized in table 39. Markup on total costs incurred through the distribution system for explosives was assessed at 25 percent; for black and smokeless powders a total markup of 90 percent was assumed. This estimate is based on analyses of costs and price at each level supplied by an integrated powder distributor. Table 39 sets forth the net cost added by the distribution network and further summarizes the net cost to explosive users from both manufacture and distribution for the various explosive categories. To illustrate the effect that the method of program implementation can have (taggant batch size and treatment of waste), costs for the five cases previously defined for the cap-sensitive high explosives are shown. Case 4 is, as noted, the OTA baseline case.

Table 39.—Distribution System—Summary of Cost Added and Markup (cents per pound)

Explosive category	Total cost leaving manufacturing facility	Distribution system cost added	Distribution system markup	Total cost added by distribution system	Total added price to user
Cap-sensitive packaged high explosives:					
Case 1	8.5	0.2	2.2	2.4	10.9
Case 2	6.6	0.1	1.7	1.8	8.4
Case 3	5.6	0.1	1.4	1.5	7.1
Case 4 (baseline)	4.8	—	1.2	1.2	6.0
Case 5	2.9	—	0.7	0.7	3.6
Boosters	22.9	0.2	5.3	5.5	28.4
Black powder	8.3	1.4	6.2	7.6	15.9
Smokeless powder	6.3	38.8	[illegible]	54.4	[illegible]
Detonating cord	[illegible]	—	0.2	0.2	0.6
Blasting caps	5.0	—	1.2	1.2	6.2

SOURCE: Office of Technology Assessment.

USER COST IMPACTS

The cost increases estimated to occur as a result of the baseline taggant program are summarized and their impact on users analyzed.

Increased Material Costs

The net cost increase due to tagging explosives is summarized here. Summary cost impacts include:

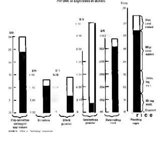
- the cost of identification taggant materials,
- the cost of detection taggant materials,
- manufacturing costs added, including markup, and
- distribution network cost effect including markup.

The following increases are noted for the baseline cost:

Explosive category	Percent cost increase
Cap-sensitive packaged high explosives	11.9
Boosters	[illegible]
Black powder	2.3
Smokeless powder	11.8
Detonating cord	23.8
Blasting caps	18

The individual contributing cost elements to the overall cost impact are illustrated in figure 18 for the respective explosive categories.

Figure 18.—Summary of Added Costs to Explosive Users Cost Per Unit of Explosives in Dollars



SOURCE: Office of Technology Assessment

For the baseline case, the overall average increase in price due to tagging is on the order of 12.8 percent, the weighted average for each of the above percentage contributions. The estimate of absolute annual cost increase in explosives is approximately $37 million.

Commercial Uses of Explosives and Gunpowders—General

Who uses commercial explosives and gunpowders? Over 55 percent of the total weight of explosives and blasting agents is utilized in the mining of coal, both in underground and surface mining operations. Quarrying and nonmetal mining are next in rank (15.4 percent), followed closely by metal mining (14.6 percent). Construction work at 10.6 percent and "other uses" at 4.2 percent complete the spectrum of user classes as adopted by BOM's annual "Minerals Industry Survey." Onsite investigations were conducted for each of the major user classes in order to determine the order of magnitude cost and economic impact to the users of tagged high explosives. The selection of users investigated included both underground mining and surface mining, as each type differs in the relative utilization of high explosives. Onsite investigations were conducted with the following users during the course of the study:

Underground mining
  Metal mining (copper)—Anaconda, The Crow Fork Mine, Utah
  Coal mine—Webster Coal Co., Kentucky
Quarry
  Tri-State, Maryland
  Rockville Crushed Stone, Maryland
Surface mining (open pit)
  Metal mining (copper)—Kennecott, Bingham Canyon Mine, Utah
Construction work
  Guy F. Atkinson, California

The following sections describe the findings of the limited number of intensive investigations of the above explosive users.

Underground Mines

The Crow Fork (Anaconda) Mine near Tooele, Utah, is a large, deep underground operation in hard-rock mining for essentially high-grade ore. The mine will primarily produce copper, although significant amounts of silver, gold, and molybdenum are expected as byproducts. This mine is still under development and has had no production of ore as yet. Mine reserves are estimated at 20 years with an estimated production output capacity of 10,000 tons of ore per day. The total use of explosives is projected to be approximately 0.6 percent of total operating costs. Approximately 80 percent of the explosives used are noncap-sensitive gels and blasting agents such as ANFO. The remaining 20 percent of explosives, including dynamites, slurries, boosters, detonators, and detonating cord, would be subject to a tagging requirement if taggant legislation were enacted. A 12.8-percent boost in the cost of tagged explosives would translate into a 0.02 percent increase in the cost of mining, certainly not a significant cost increase. The use of ANFO is currently related to cleanup and aboveground excavation. Steady-state underground mining in the future can be expected to change the explosive mix and potentially increase the cost increase noted above. If all explosives used in the future were the cap-sensitive types, a taggant program would increase mining costs less than 0.1 percent.

The cost impact on underground coal mining is somewhat higher. At present, the cost of the cap-sensitive slurry and detonators (the explosives used to mine the coal) represents approximately 1.4 percent of the total cost of bringing the coal out of the ground. The increase in the cost of the explosives due to tagging would increase operating costs less than 0.2 percent. Other economic factors far outweigh increases of this sort.

Quarries

Discussions with the Rockville Crushed Stone Quarry revealed that explosives contribute to slightly over 4 percent of the gross total costs of operation. Between 1.5 million and 1.75 million lb of cap-sensitive (80 percent) and noncap-sensitive (20 percent) explosives are utilized annually at this location. Since the environment is wet, no ANFO is currently utilized. The blasting activity is all contracted with a local blasting jobber who provides the drilling, explosives, and blasting operation. The cost impact of an increase due to a tagging program is thus significantly higher in this explosive intensive operation. However, the increase would still be less than 1 percent of operating costs. If the costs of explosives, caused by legislation of a tagging program, are much higher than estimated for the baseline program, then the quarry might investigate the cost potential of using inexpensive blasting agents, coupled with a water pumping operation.

A quite different situation is provided by the quarry operated by Tri State Explosives. The Tri State Quarry produces "facing" stone in various grades. The use of explosives in the operation is relatively insignificant, averaging from 10 to 15 blastings per year. Between 15 to 105 lb of explosives are used in each blasting, characterized as a very precise operation. The incremental cost of tagged explosives is therefore trivial.

Open Pit Mines

The OTA study team visited the Kennecott "Bingham Canyon Mine" near Salt Lake City, Utah. This open pit mine has many distinctions, including:

- the world's largest manmade excavation,
- the first open pit mine in the copper industry (started in 1904),
- the largest single mining operation ever undertaken, and
- the holder of the largest copper production record of any individual mine in history.

Figure 19 shows a photograph of the Bingham pit. Each vertical terrace is approximately 50 ft high. The mine is an extremely large user of explosives, with approximately 105,000 lb of explosives used per day or over 38 million lb/year. For every pound of explosives used, 4.2 tons of material are mined. Cap-insensitive explosives predominate, the utilization consisting of almost 80-percent ANFO and almost 20-percent cap-sensitive slurry. Explosive costs run from 3 to 5 percent of total operating costs. High explosives, although a small percentage of the total weight of explosives used, account for 7 to 10 percent of costs for all explosives used in the mine. Large amounts of primacord are used together with boosters, detonators, and some dynamite for secondary blasting (e.g., breaking up boulders). High explosives therefore contribute on the order of 0.3 percent of the total cost of operation. The cost increase for a baseline taggant program would be on the order of 0.03 percent of operating costs.

Construction

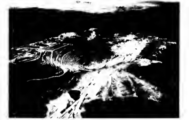
The study team discussed the impact of tagged explosives with the Guy F. Atkinson Co. in South San Francisco, Calif., a large contracting firm that utilizes large quantities of explosives in both underground (tunnels, etc.) and aboveground construction operations. In recent years the firm has utilized on the order of 20 million lb of explosives annually. In underground applications, operating costs are considered to be very sensitive to the cost of powder. Values placed on underground operations were:

	Pounds of powder to remove yd³	Cost per yd³
[illegible]	3/4 lb	$3.00
[illegible]	1/4 lb	17
Hard-rock	1 lb	50¢

In a recent tunnel application, Guy F. Atkinson used approximately 300,000 caps in the construction of a 22-mi tunnel. At an estimated 50 cents/cap, the value of caps alone amounted to approximately $150,000.

In aboveground work, Guy F. Atkinson recently utilized over 40 million lb of explosives in the construction of the Melones Dam in California. This fixed price contract was very

Figure 19.—Bingham Canyon Open Pit Copper Mine



[illegible]

powder intensive. The value put on explosives was approximately 9 percent of operating costs, consisting of 70 percent cap-sensitive explosives and 30 percent ANFO.

A baseline taggant program would increase operating costs approximately 1 percent, a significant cost but probably not sufficient to cause a shift to alternative excavation methods. One additional potential impact should be noted. Such construction projects are normally long-term, fixed-price contracts. A sharp jump in the cost of explosives during the course of the contract could significantly affect profits.

A summary of the findings on current explosive cost contributions to the various user classes is shown in table 40. Explosives percentage contributions to operating costs vary (dependent on user type) from less than 1 percent (underground metal mining) to as high as 9 percent (from construction example). As a result, the cost impact of an increase in the price of cap-sensitive high explosives will vary, particularly as these explosives represent varying portions of the total explosive mix used.

Hand loading

The above cost impact calculations were for industries that are generally able to pass on increases in the cost of operations to their customers. Handloaders, however, are the ultimate users of the product and must absorb

Table 41.—Current High Explosives Cost Impact for Various User Classes

	Percent of operating costs	Percent increase in operating costs due to taggant program
Underground metal mining	0.2b	0.00
Underground coal mining	.4c	.02
Open-pit metal mining	1.2 to 1.5d	.003
Quarries	6	0
Construction		
Aboveground dam construction	0.1	0
Excavation—general	2 to 3	
Tunneling	5	—

aAssumes [illegible] taggant version.
bTotal Operating costs [illegible] were not available for [illegible]
[illegible] or less than [illegible] percent of costs.
NOTE: This data point reflects a [illegible]
cExcludes [illegible]
dIncludes [illegible]
SOURCE: Office of Technology Assessment.

any increased cost due to a taggant program. Handloaders load their own ammunition for two reasons—economy and the hobby aspect. A less than 10-percent cost increase in expendable material is unlikely to affect a hobby for which hundreds of dollars in costs have already been incurred (hand loading equipment and guns). As powder is only one of several materials on which a hand loader saves costs (cartridge cases, projectiles, wadding) and additional cost savings are realized from labor and avoiding paying the excise tax on purchased ammunition, an 8-percent increase in powder cost would translate into a very few percent increase in total reloading costs.

OTHER COST IMPACTS

Government Investigation Costs and Program Administration

BATF has estimated[11] a requirement of 11 man-years of effort annually to enforce the provisions of S.333, primarily to establish standards and monitor implementation of the taggants program. Estimated program costs in fiscal year 1979 dollars for this level of effort are approximately $500,000. This would include several explosive specialists, chemists, inspectors, and clerical help. Estimated costs for actually investigating taggant tracing services are expected to be marginal beyond current BATF personnel levels and are contained in the above estimate. Their current tracing service personnel would require one additional slot at a cost of approximately $30,000. The total annual costs estimated for BATF are therefore just over $500,000.

Completing the spectrum of Government-level costs are those expenditures that are budgeted and projected to complete the technical development of the taggants program by the Aerospace Corp. Total program costs (including sunk costs of $5.4 million prior to fiscal year 1980) are $10.0 million budgeted. Projected outyear costs are estimated at $4.8 million.

Investigative Costs

Investigators of bombing incidents currently devote considerable time to examining explosive debris for clues regarding the type and source of the explosive material. Further effort is devoted to forensic analysis at the laboratory level. If an identification taggant program is implemented, collection of debris for a laboratory search for taggants will become part of the standard bombing-scene investigatory procedures. There should be little or no impact on the time required for a bombing scene investigation. Taggant recovery from the debris will be an additional laboratory exercise, but it could well replace the more time-consuming procedures now carried out to obtain less information than would be furnished by taggants. Similarly, it will take time to follow up on the leads furnished to investigators by having a list of last legal purchasers of the bomb's explosive material, but that time is probably less than would be expended following up less direct leads. For purposes of this study, the assumption was made that a taggant program would have no net cost effect on investigation time.

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[11] Atlas Powder [illegible] testimony, September 1977, p. 5-20.5

Effects of Competition-Substitution

Depending on the ultimate cost increase in the price of explosives to the user community due to the addition of taggants, a variety of economic impacts could occur. As has been pointed out earlier, the choices of the type of explosive purchased by users are frequently made on the basis of the lowest price rather than brand loyalty. Since there are various kinds of potential substitution threaten the explosives industry if the user perceives more economical choices available to him. For instance, in the underground mining of coal, the cost of explosives can play a predominant role in the overall cost of operations, particularly in marginal types of mining operations. Substitution of mechanical coal mining equipment could essentially eliminate the use of explosives in these mines. The cost impact of the baseline taggant program is unlikely to significantly affect that type of choice, particularly given the capital investment in machinery that is currently used to support explosive mining. A full economic cost tradeoff analysis between mechanical tools and the increased cost of explosives would need to take place for a meaningful sample size of users to determine the net effect on the explosives industry.

Discussions with a dynamite and packaged slurry manufacturer revealed that in one case a recent 5.4-percent increase in the price of a slurry product resulted in several buyers shifting to other products—a loss in sales of 6 million lb of product for that manufacturer. Other estimated potential losses by substitution were suggested by the manufacturer. For instance, given a price increase of $1.00/100-weight in their nitroglycerine-based products, that manufacturer estimated that as much as 25 percent of their business would shift to other booster/slurry combinations. The manufacturer further estimated that if a 10-cent increase in the price of packaged slurries occurred, they could lose 50 percent of their slurry business to ANFO, as mining operations would substitute borehole dewatering (dry pumping the hole and using a borehole liner) coupled with ANFO. This kind of substitution for cap-sensitive packaged high explosives to ANFO was also noted by an explosives jobber (operating in a quarry environment) as a highly likely prospect should the cost of tagged explosives increase noticeably. The accuracy and objectivity of this type of unsubstantiated estimate are open to question, particularly as other operators expressed opposite views. Safety, reliability, and ease of handling were cited as reasons why a cost increase such as would occur in the baseline tagging program would not cause a product substitution. The examples do, however, highlight a very real potential problem, particularly if the taggant program were to substantially increase the cost of cap-sensitive explosives, or if a program were adopted that included tagging some portion of a cost-competitive segment of the industry (such as tagging dynamite and not pea and slurries).

It is noted that the current annual utilization of ANFO in the country is on the order of 3.4 billion lb. It is estimated that the trend toward utilization of ANFO has gone about as far as it can go, given the excellent economics for ANFO in a wide variety of circumstances. Increasing inordinately the cost of explosives due to tagging could, however, further shift current utilization from cap-sensitive packaged explosives to ANFO.

Effects on Fixed-Price Commodities

There is a potentially important economic spillover on the marketplace for fixed-price commodities, due to taggants. Copper prices are established in a competitive worldwide market setting. The Kennecott copper mine, for instance, competes in this environment and as a result is limited in its ability to pass on additional costs of operations. Tagged explosives could affect this situation, depending on the degree of tagging implemented and the cost of tagging. The OTA analysis revealed that only insignificant influences on cost of operation would take place due to cost increase from a mandated taggant program. If ANFO and unpackaged slurries were also tagged, however, the impact could be quite different. The price of ANFO could approximately double, raising the cost of operations as much as 4 percent. Such an increase may well require a higher grade cutoff point for ore, resulting in a significant decrease in the effective reserves of economically recoverable copper at that site.

Possible Removal of Some Gunpowders From the Market

The initiation of a tagging program involves startup costs to the manufacturer which this analysis has assumed would be amortized over 10 years and passed along to the consumer in the form of somewhat higher prices. It is possible, however, that some manufacturers of black or smokeless powder might prefer to take some product lines off the market so as to incur these startup costs for only a portion of their existing product lines. It is also possible, though perhaps less likely, that a manufacturer might choose to halt all production for the handloader market rather than be involved in tagging such powders. If this should occur, handloaders would find their existing choice among powders reduced. This reduction in choice would be a cost to handloaders, though not one which can be expressed in dollars.

TAGGANT PROGRAM COST SYNTHESIS

In this section of the report, cost estimates are established for implementing a baseline taggant program. This development of cost is an accumulation of total program cost elements developed in prior sections of the report. The program cost elements include:

- identification taggant material costs;
- detection taggant material costs,
- manufacturing level costs,
- distribution system costs, and
- public overhead costs:
  - — sensor-related production
  - — sensor development
  - — other taggant program development costs, and
  - — BATF annual administration and tracing activity.

Subsequent to the buildup of the total baseline taggant program costs, a series of alternative implementation levels are examined for their cost impact. Costs are estimated for a total taggant program and for separate identification and detection taggant programs. Following that are set forth the various aspects of cost uncertainty in the study and a cost sensitivity analysis of key uncertainty cost drivers or parameters intrinsic to the taggant program.

Identification Taggant Program Material Costs

Table 41 shows the buildup of identification taggant material costs. The calculations, which are self-explanatory, are based on the program needs (weight level, usage) set forth in the earlier section on Taggant Material Costs. A price for polyethylene encapsulated tags of $55/lb is utilized with the concentration noted. The total annual cost for the baseline condition is $11,200,000.

Detection Taggant Program Material Costs

Table 42 sets forth the buildup of detection taggant program material costs. The calcula-

Table 41.–Identification Taggant Material Annual Costs: Baseline Program

	Estimated annual production	Explosive average unit cost	Taggant concentration	Encapsulated/nonencapsulated (total pounds)	Taggant cost per pound	Increased cost per unit of explosives	Increase in explosive cost	Annual cost for taggant materials (dollars in thousands)
Cap-sensitive packaged high explosives	326 million lb	$0.50/lb	0.05%	Encapsulated (162,500)	$55	2.75¢	5.5%	$8,[illegible]
Cast boosters	8 million lb	$1.60/lb	0.1%	Encapsulated pellets (8,000)	102	10.2¢	[illegible]%	730
Smokeless powders	5 million lb	$4.00/lb	0.05%	Encapsulated (2,500)	55	2.75¢	0.69%	137
Black powder	400,000 lb	$2.00/lb	0.05%	Encapsulated (200)	55	2.75¢	0.30%	[illegible]
Detonating cord	500 million ft	$5/ft	5 taggants per inch	Encapsulated ([illegible])	25/batch	[illegible]	[illegible]	250
Blasting caps	86 million units	50¢ each	50 mg	Encapsulated (9,380)	120	1.32¢ ea.	2.64%	1,100 (+[illegible])
Total program								$[illegible]

[illegible]

SOURCE: Office of Technology Assessment

Table 42.–Detection Taggant Material Annual Costs

Explosive category	Estimated annual production	Detection taggant level concentration	Detection taggant required, pounds	Taggant cost per unit explosives ($[illegible] lb taggant)	Expected total annual costs (dollars in thousands)
Cap-sensitive packaged high explosives	326 million lb	0.125% by weight	407,500	[illegible]	$3,250
Cast boosters	8 million lb	0.125% by weight	1,500	[illegible]	80
Smokeless powders	5 million lb	0.125% by weight	1,250	[illegible]	50
Black powder	400,000 lb	0.125% by weight	100	[illegible]	4
Detonating cord	500 million ft	[illegible] mg/ft	[illegible]	[illegible]	4,500
Blasting caps	86 million units	200 mg per cap	38,000	1.76¢	1,474
Total					$9,340

SOURCE: Office of Technology Assessment

tions, which are self-explanatory, are established at the noted concentration levels and weights, feet, and unit quantities common to the identification taggant program. At the estimated cost of $40/lb of detection taggant material, the total annual program estimate is $4,340,000.

Manufacturing Level Program Costs

Explosive manufacturing level program costs are delineated in table 43. The annual cost estimate for the baseline program is $7,082,500. The costs are based on explosive quantities and manufacturing incremental costs developed in previous sections.

Distribution Network Program Costs

The annual program cost attributable to the distribution network is $8,231,000. The calculation shown in table 44 is based on the quantities of explosives and distribution system incremental costs established in previous sections.

Public Overhead Program Cost

Public overhead program costs are defined to include the following cost elements:

- sensor-related deployment costs,
- taggant program development and

Table 43.—Manufacturing Cost Added[a]

Explosive category	Estimated annual production	Manufacturing cost added/unit	Total program manufacturing cost added (dollars in thousands)
Cap-sensitive packaged high explosives	325 million lb	1.03¢	$3,347
Boosters	6 million lb	7.72¢	463
Black powder	400,000 lb	2.57¢	[illegible]
Smokeless powder	5 million lb	2.57¢	24
Detonating cord	500 million ft	0.094¢	470
Blasting caps	64 million units	4.0¢	2,560
Total			$7,060

[a] Baseline scenario.

SOURCE: Office of Technology Assessment.

Table 44.—Distribution System Cost Added[a]

Explosive category	Estimated annual production	Distribution system cost added/unit	Total program distribution system cost added (dollars in thousands)
Cap-sensitive packaged high explosives	325 million lb	1.196¢	$3,891
Boosters	6 million lb	6.4¢	384
Black powder	400,000 lb	7.5¢	30
Smokeless powder	5 million lb	64.43¢	3,222
Detonating cord	500 million ft	0.14¢	700
Blasting caps	64 million units	0.27¢	173
Total			$8,232

[a] Baseline scenario.

SOURCE: Office of Technology Assessment.

- BATF administrative costs, including licensing activity

The annual sensor program cost is $8.63 million for the baseline case in which 1,500 units are deployed in an assumed mix of 90-percent MS and 10-percent MS sensor types. As indicated earlier, the annual BATF administration cost is approximately $0.53 million, while the taggant program development annual cost is estimated at $1.15 million, for a total of $9.51 million.

Taggant Program Baseline Cost Estimate

The total estimated cost for the baseline taggant program is $45.37 million per year. The calculation of this estimate is shown in table 45. It includes the estimated cost impact of taggant materials (identification and detection), manufacturer added cost, distributor added costs, and public overhead (sensors, taggant development, and BATF administration).

Table 45.—Taggant Program Summary Annual Cost-Baseline Program (millions of FY 1979 dollars)

	Annual cost
Taggant materials	$22.56
Identification taggants (11.72)	
Detector taggants (9.34)	
Sensor related costs[a]	8.63
Explosives manufacturers added costs	7.07
Distribution costs	8.23
Government costs:	1.68
Administration and licensing	
Taggant program development	
Increased investigative costs	0
Total baseline program annual cost	$45.37

[a] Assumes [illegible] MS sensors and [illegible] MS sensors.

SOURCE: Office of Technology Assessment.

Program Cost Versus Implementation Level

Table 46 shows the major cost elements of the taggant program as a function of implementation level. The low-level program would use a unique identification taggant for each manufacturer, type of product, and year of

Table 46.—Taggant Program Summary Annual Cost Versus Implementation Level (millions of FY 1979 dollars per year)

Summary cost elements	Low case program	Baseline program	High case program
Taggant materials:			
Identification taggants	$ 5.61	$11.72	$ 122
Detection taggants	6.34	9.34	93.4
Explosive manufacturers added cost	6.26	7.07	19.4
Distribution system added cost	5.12	8.23	9.55
Public overhead	5.29	9.51	24.5
Total program annual cost	$28.6	$45.37	$311 (less ANFO)
ANFO			$187.5
			$498.5

[a] Uncompensated [illegible] cost based on [illegible] baseline estimate.

[illegible] year tagging level.

[illegible] tagging level.

[illegible]

[illegible]

[illegible]

SOURCE: Office of Technology Assessment.

manufacturers. A total of 600 detection sensors would be deployed—one for passengers and one for baggage at each airport location currently deploying magnetometers and hand baggage X-ray units. Cap-sensitive high explosives, detonators, boosters, detonating cord, and smokeless and black powders would be tagged with both identification and detection taggants. Blasting agents would not be directly tagged.

The baseline program would tag the same materials as the low-level program, but would use a unique identification taggant for each shift of each product—analogous to the current date-shift code marking on the exterior of explosives. Traceability to the last legal purchasers would be maintained, as the taggant would contain all the information needed for a BATF trace (date, shift, product, and size). Approximately 1,500 detection taggant sensors would be deployed at airports and major nonmilitary access facilities such as power plants, refineries, and Government buildings. Major police bomb squads would operate portable units.

This baseline program differs from the program proposed by the BATF/Aerospace Corporation in two respects. The most important is that a full shift of the same product (a different size would be treated as a different product) would be tagged with the same taggant rather than an arbitrary 10,000 to 20,000 lb. The practical utility result of that change is that a larger list of last legal purchasers would be produced by a trace, at least for those firms that make more than 10,000 to 20,000 lb of a product in a single shift. The second difference concerns rework. It has been assumed that a special taggant containing a "composite code" will be added to material containing more than 10 percent reworked material; such a taggant would indicate that other codes in the explosive were contaminants and could be ignored.

The high-level program would uniquely tag each 10,000 lb batch of explosive and each 2,000 lb batch of gunpowder. All explosive materials, including blasting agents, would be directly tagged. Ammonium nitrate fabricated for use in ANFO would be tagged, but not fertilizer-grade ammonium nitrate. Approximately 5,000 detection taggant sensors would be deployed at every major transportation facility, controlled-access facility, Government facility, and other potential high-value targets such as campus computer locations. Portable units would be routinely available to police bomb squads. The taggant level and types of explosives to be tagged in the high-level program correspond to a strict interpretation of S333 as propounded by IME.

Program Cost of Separate Identification and Detection Taggant Programs

The above discussion has been for a program that includes both identification and detection taggants. Its cost has been expressed in the cost of each program separately. The total cost and breakouts by cost elements are discussed for each of the three implementation levels. For the baseline set of conditions, the cost breakout is set forth in table 47. These costs are, in summary:

Identification taggant program	$24.8 million
Detection taggant program	$25.4 million
Total combined program	$41.37 million

Table 47.—Identification Taggant and Detection Taggant Program Cost Comparisons—Baseline Case (in millions of dollars per year)

Program cost elements	Identification taggant program	Detection taggant program	Baseline combined program
Taggant materials	$11.22	$6.84	$21.96
Sensor-related costs	—	8.13	8.13
Manufacturers' cost	6.76	.94 Markup 4.82 Labor and testing	7.07
Distribution system cost	6.66	2.82 Markup — Labor and testing	9.23
Government cost			
Administration and tracing	.53	.10	.53
Taggant program development	.54	.6	1.15
Total	$24.79	$25.44	$41.37

[a] For 1,500 sensors.
[b] 100% markup on detection taggant.
[c] Assumed 75 percent of combined Program.

SOURCE: Office of Technology Assessment.

As one can note, the sum of individual programs is greater than the total combined program. This follows from the fact that each of the programs shares certain labor and capital resources in the combined program and each option bears the total cost for these resources if only one of the programs would be implemented. Shared resources in the combined program are approximately $5 million/year. The detection taggant program is directly sensitive to the number of deployed sensors; variation in this would affect the cost differentials significantly.

Similar cost breakdowns were calculated for the separate identification and detection taggant programs at the low and high implementation levels; these separate costs for the three implementation levels are summarized in table 48.

Table 48.—Summary Program Costs Versus Level of Implementation

	Identification	Detection	Total combined program
Low	$ 403	$2752	$3955
Baseline	2479	2544	4537
High	21454	6528	2883

[a]Combined program costs are less than the sum of the individual program costs because of shared resources.

SOURCE: Office of Technology Assessment.

Comparison of OTA Cost Estimates With IME and Aerospace Corp Estimates

In testimony before the Senate Governmental Affairs Committee, IME has estimated that the cost of the identification taggant program would be on the order of $700 million/year. That estimate includes the cost for the taggant materials, library maintenance fees, and record keeping costs. The estimate did not include public overhead cost, manufacturing added costs, costs through the distribution chain, and markup. In addition, the IME estimates for the quantity of cap-sensitive explosives produced is lower than the OTA estimate by 50 million lb. IME does not include the effects of tagging 5 million lb of smokeless powder and assumes that the total production of 2.5 million lb of black powder would be tagged. All but 400,000 lb of the black powder is used as a raw material input to other manufactured items, such as fuses, however, and so would not be tagged.

For a taggant program with the scope assumed by IME, OTA estimates the cost would be $214 million, not $700 million. The major reasons for this difference are: IME assumed material cost for the identification taggants of $200/lb (versus the OTA estimate of $55/lb); the inclusion of a library maintenance fee of $100/year per unique taggant (the fee would not be charged); and a concentration level of 0.05 percent for nonencapsulated taggants versus the 3M/Aerospace suggested level of 0.025 percent (equivalent to a 0.05-percent concentration level for encapsulated taggants). As indicated previously, the IME figures for the material and library maintenance costs reflect a 3M quoted cost for taggants produced in a pilot program.

Table 49 depicts the various cost elements for an identification taggant program that includes blasting agents. The three columns show, respectively, the element cost estimates made by IME, the corresponding costs under the same assumptions made by OTA, and the actual cost elements, as estimated by OTA. It must be clearly understood that these cost esti-

Table 49.—Comparison of the Estimates for ID Tags (millions of dollars per year)

Cost element	IME cost estimate	OTA estimates using IME assumptions	OTA estimates using OTA assumptions
ID tag materials—non-ANFO	$ 320	$ 139	$ 11.2
ID tag materials—ANFO	340.0	48.0	68.0
Manufacturing costs—non-ANFO	—	17.2	9.47
Manufacturing cost—ANFO and recordkeeping	—	102.0	102.0
Distribution system cost	—	6.0	3.58
Public overhead	—	.87	.82
Record keeping costs	11.5	In mfg. & distribution	In mfg. & distribution
Code reservation	28	—	—
Total	$700.3	$308.95	$214.54

[a]Assumes 775 million lb of explosives produced; 2.5 million lb of black powder; smokeless powder not included.

SOURCE: Office of Technology Assessment.

materials for the identification tagging program for the high implementation level.

The Aerospace Corp. cost estimate of approximately $48 million/year was for a different program—one in which ANFO and other blasting agents are not directly tagged. As noted above, the program for which the Aerospace Corp. cost estimate was given is quite similar to the OTA-modified baseline program, differing only in the size of the unique taggant batch and in some assumptions on rework material.

A summary of major differences between the Aerospace Corp. assumptions and the OTA baseline case assumptions is as follows:

	Aerospace assumptions	OTA assumptions
Batch size	12,000,000	500,000 lb
Number of sensors deployed	5,000	1,500
Increased investigating costs	$5.4 million	None
Marking	No	Yes
ID tag material cost, microencapsulated	$60/lb tag	$57/lb tag
Detection tag material cost	$80/lb tag	$40/lb tag

Table 50 depicts the various cost elements for an identification and detection taggant program that does not include blasting agents. The columns represent, respectively, the cost estimates made by the Aerospace Corp. and the cost elements as estimated by OTA.

Table 50.—Comparison of OTA and Aerospace Program (Option 2) Estimate

Cost elements	Aerospace estimate	OTA estimate
ID tag materials	$9.50	$11.20
Detection tag materials	7.85	8.34
Labeling	2.15	—b
Relabeling	1.67	—b
Total manufacturing cost	22.50	0.69
Increased investigative costs	5.40	—b
Explosives monitoring cost	(a)	7.87
Distribution system cost	(a)	5.23
Government costs	c	1.12
Total	$48.04	$43.67

[a] See Explosives Tagging: Production/Distribution, Aerospace Corp.
[b] Included in explosives manufacturing cost.
[c] Not included in cost.

SOURCE: Office of Technology Assessment.

In summary, the question as to which cost estimate is correct, that by Aerospace or that by IME, cannot be simply answered, as they are giving estimates for different levels of implementation. Both estimates contain values for cost elements that are not currently relevant, and these are clearly indicated in tables 49 and 50.

Who Bears the Cost of a Taggant Program?

For the baseline program set of conditions, an analysis was made to determine which of the various segments affected would bear the costs of the taggant program. Table 51 shows the cost breakout. Sensor-related costs would reflect the perceived utilization of sensors at airports for screening of persons, hand-carried baggage, and checked baggage. For the baseline case of 1,500 sensors, 1,200 or 80 percent are assumed to be employed at airports, with 300 or 20 percent in Government buildings, courthouses, transportation centers, and police bomb squads.

The users of explosives absorb the primary impact of the program, assuming that all costs associated with the taggants (material, manufacturing, and distribution) are passed on to the various classes of users examined. The extent to which these costs will ultimately impact on consumers of goods produced by the explosive users is uncertain.

Public overhead costs of administration and taggant program development are borne directly by the taxpayer, who would also bear some portion of the detection taggant sensor deployment in the baseline case.

Table 51.—Taggant Program Cost Impact by Who Will Bear the Cost (millions of dollars by impact segments)

Baseline program costs	Users of explosives	Taxpayers	Airline users	Total
Taggant materials	$20.56			$20.56
Sensor-related costs (for native manufacturers)	—	$0.88	$5.53	6.41
Explosives monitoring	7.07			7.07
Distribution system costs	9.23	—	—	9.23
Public overhead	—	1.66		1.66
Total	$36.86	$2.54	$5.53	$44.93
Percent of total	82%	6%	12%	100%

SOURCE: Office of Technology Assessment.

COST ANALYSIS PRECISION

In the preceding narrative description of the taggant program cost analysis, OTA has set forth the basis for estimating the various factors in the total program cost equation. The relative certainty (or precision) of the estimates has been addressed in varying degrees. In this section, OTA specifically summarizes concerns regarding the precision of the estimates and the related implications for 1) the reasonableness of the estimates and 2) the prospects for cost estimate growth or stability.

A precise evaluation of the costs of a taggant program is not possible due to the current state of development of the taggants and sensors and the uncertainties in how a taggant program would be implemented. Pilot testing has been conducted between the identification taggants and several of the types of explosive materials proposed to be tagged (cap sensitive packaged explosives, boosters, and black powder); testing is underway on smokeless powder; and no pilot tests have been conducted for detonating cord or blasting caps. Three candidate sensors are being evaluated, but no system has progressed past the laboratory stage. Various implementation levels are possible, each of which directly affects costs. Examples of critical implementation decisions include which explosives will be tagged, what would constitute a unique batch with a unique identification species, and how many of which type of detection sensors would be deployed.

Several forms of cost uncertainty analysis are possible. Given a baseline case, one can examine the cost effects of changes in individual cost factors and note the contribution on total program cost in a deterministic manner. This method is employed in the following section in order to highlight the primary cost drivers in the taggant program. Another method treats costs in a probabilistic manner. Additional data would be required to implement this procedure.

Cost Sensitivity Analysis

The method used here essentially sets forth the cost impact changes that occur due to variations in cost-driving variables of interest. The cost impact variations from an established or hypothesized baseline case is the traditional method taken. Cost element changes of absolute or percentage terms are set forth and the impact on total program cost is noted. Since the taggant program is in the early stages of development, the factors in the total cost equation need to be examined to determine the potential ranges of variance from an established baseline. Table 52 includes a relatively comprehensive list of elements that have an influence on the program cost estimate. These include the various factors (both cost and related requirements) for:

- taggant materials;
- the manufacturing and distribution system;
- public overhead (sensors, administration, taggant program development); and
- programmatic considerations.

Taggant Materials

IDENTIFICATION TAGGANTS

Various factors can further influence the cost of identification taggant material. The best estimate from 3M is based on their recent lifetime study: $75/lb of unencapsulated taggants in 2.5- to 5-lb lots. This value is based on tagging 900 million lb of explosives per year requiring a guarantee of manufacturing of 150,000 lb of taggants per year for a minimum of 2 years. Values utilized in the OTA study are based on lower quantities of encapsulated taggants. 3M has made their best estimate of this effect on cost; however, more detailed study would be required by them to provide an equivalent confidence to the current $75/lb quotation. Encapsulated taggants estimates provided for this study are targeted at $55/lb of polyethylene coated taggants for 30,000 lb of taggants per year. Additional study of opaque

Table 52.—Elements of Cost Uncertainty

Identification taggant material
- Taggant cost dollars per pound
  - Encapsulation: melt-opaque capsule
  - Yield from encapsulation process
  - Cost is an estimate, not a contracted value
  - Monopoly issue
- Taggant concentration level
- Quantity of explosives to be tagged
  - Cap-sensitive packaged explosive
  - ANFO and other blasting agents
- Taggant waste

Detection taggant material
- Molecule prices
- Encapsulation cost
- Concentration levels
- Quantity of explosives to be tagged

Sensor cost
- Quantity of sensors to be deployed
- What type sensors will be successfully developed?
- What will be the mix of deployed sensors?
- Development cost uncertainty
- False alarm rate
- Production price uncertainty

Explosive manufacturers added cost
- Record keeping costs (particularly smokeless powders)
- Testing and labor cost for explosive categories not pilot tested (powders, detonating cord, blasting caps)
- Batch size
  - Productivity
  - Waste
- Taggant inventory costs
- Markup and degree to which costs are passed on

Distribution costs

Recordkeeping
- Storage
- Markup levels

Cost of investigation
- Cost penalty vs. cost savings

Government regulation and administration

Implementation and programmatic
- Level of implementation
- Start-up program costs
  - Identification taggant program
  - Detection taggant program

SOURCE: Office of Technology Assessment

type encapsulation is required in order to realize the $55/lb estimate. 3M's assessment of the worst case is $79/lb to account for the uncertainty in:

- encapsulation and encapsulation process yield (further research is required to define these parameters), and
- ultimate contractual conditions specified (the only basis for "precise" quotations).

3M believes that the worst case estimate is highly unlikely and was provided to the study group to permit the cost uncertainty analysis of the taggant program. The ultimate effect of the worst case condition would be to increase identification taggant direct costs of materials by 27 percent.

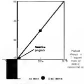
If one were to implement nonencapsulated taggants, as was studied in some detail in the baseline study, the ultimate effect would be a reduction in the baseline program estimate from $11.2 million to $9.5 million, a reduction of approximately 14 percent.

Other areas of cost uncertainty are:

- Monopoly issue—this is discussed in the second section of this chapter.
- Taggant concentration levels—the survivability and recovery tests so far conducted have been at one concentration level, as have the safety tests. The tests have identified areas where the taggants survive and areas where individual taggants do not survive (with a substantial gray area). Nonsurvival seems to be primarily a function of the thermal or physical decomposition of the taggant materials, which would be essentially unaffected by concentration level. If concentration levels were changed, the cost of material would increase almost linearly (see below).
- Quantity of explosives to be tagged—greater quantities (over 325 million lb of cap sensitive) of tagged explosive would decrease cost per pound of taggant material; however, total program increases would not increase linearly.
- ANFO tagging—see the section on "Taggant Program Cost Synthesis" for estimated effects. It is probable that if ANFO were to be tagged, a taggant with additional layers would require development to permit the larger number of codes required by the large quantities of ANFO and other blasting agents.
- Taggant waste—the degree of taggant waste (if any) in a production environment is unknown; this factor, which is not considered significant, would tend to increase taggant material cost estimates.

Summary baseline program cost sensitivity to variations in identification taggant material costs or concentration levels is depicted in figure 20. Cost impact changes include the effect of markup at the manufacturing level and throughout the distribution network.

Figure 20.—Baseline Program Cost Sensitivity Impact With Changes in Identification Taggant Material Cost, and Concentration Level



SOURCE: Office of Technology Assessment.

DETECTION TAGGANT MATERIALS

Detection taggant materials are still in the exploratory stage of development with five candidate molecules currently under consideration. As shown in our discussion in the second section, estimates based on recent budgetary and pricing quotations vary depending on the molecule and the spread in the submitted cost estimates. The average value utilized in this study is $45/lb. The range of estimates is from $22 to $58/lb. The uncertainty in program dollar terms is as follows:

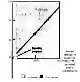
Baseline program	$8.34	million
Optimistic estimate	$5.14	million
Worst case estimate	$13.54	million

Concentration levels are another issue. Current expectations are that 0.025-percent concentrations are adequate. Further development testing is required in order to determine this parameter. Baseline program cost sensitivity due to a range of variation in detection taggant material and/or concentration levels is set forth in figure 21. Cost variations include the progression of markups that are estimated at the manufacturing level and throughout the distribution network. It should be noted that the concentration levels for identification and detection taggants are inconsistent with a very small concentration of identification taggants assumed and a very high concentration of detection taggants.

THE MANUFACTURING AND DISTRIBUTION SYSTEM

Taggant program cost estimates at the manufacturing and distribution levels vary in their degree of precision and are highly influenced by various assumptions that are required due to the lack of substantive empirical data. Confidence is relatively higher in the estimates

Figure 21.—Baseline Program Cost Sensitivity Impact With Changes in Detection Taggant Material Cost, and Concentration Level



SOURCE: Office of Technology Assessment.

where pilot testing has been accomplished (e.g., cap-sensitive packaged explosives). The degree to which costs will be passed on with associated markups through the distribution network to the user of explosives is another area of uncertainty.

As a result of the pilot test program, reasonable data is available for the analysis of the cost impact of adding taggants to the manufacture of cap-sensitive high explosives, at least for those companies that participated in the program. No similar data is available, however, on the manufacturing impact of the other types of explosive materials that might be tagged. Only gross estimates have been made for recordkeeping and storage costs.

Federal requirements for detailed sale recordkeeping currently pertain to cap-sensitive packaged explosives, boosters, black powder, detonating cord, and blasting caps. Smokeless powders, currently exempt from the requirement, represent the largest uncertainty in recordkeeping costs. OTA has treated this cost element parametrically with the level of implementation analysis. For the three cases studied, the following cost estimates were utilized:

Low program	no cost increases
Baseline	$0.004-0.40 powder
High estimate	13¢/lb powder

These estimates are based on preliminary assessments; further refinements in the smokeless powder recordkeeping estimate require a data base reflecting pilot testing experience and a detailed description of the distribution network.

An analysis of manufacturing cost impact for cap-sensitive packaged explosives revealed the following cost sensitivity to program implementation levels:

Tag batch size	Manufacturers' cost per pound of explosives
11,000 to 12,000 lb	4.0
20,000 lb	2.3
Shift production	0.81
Plant year	0.3

Uncertainty in other potential explosive types and sensors will persist until a particular program level is recommended for implementation.

Taggant inventory costs, which were assessed as part of the manufacturers' costs, were estimated at 10 percent interest for a taggant inventory supply of one-half year. Variations from this assumption would have relatively minor influence over total program cost effects. Markup costs were estimated at 10 percent at the manufacturing level and 25 percent for the distribution network for explosives, while 90 percent markup was utilized for the black and smokeless powders in the distribution network based on estimated inputs from a manufacturer. Uncertainty exists in the degree to which taggant program costs will be passed on to explosive users, since ultimately these markups would be determined in the marketplace.

PUBLIC OVERHEAD

Sensor-related costs.— Considerable uncertainty exists in estimates of the sensor program cost. These relate to:

- what type of sensors will be successfully developed?
- what will be the mix of deployed sensors?
- how many will be deployed?
- development cost uncertainty,
- production price uncertainty, and
- false alarm rates.

Table 63 delineates a set of cost possibilities where sensor mix and quantity are varied. One can note the wide spread of resulting estimates given these variations in assumptions. OTA estimated the sensor development costs at twice the level of the Aerospace estimates in se-

Table 63.—Annual Cost per Sensor for Various Mixes

		Total annual cost (millions of dollars)	
	Annual cost per sensor FY79 dollars	1,500 sensors	5,000 sensors
All CEDD	$3,3[illegible]	$5.[illegible]	$16.6
All MR	4,050	6.1	20.3
All MS	9,228	13.8	46.1
CEDD 40% MS 60%	3,900	5.8	19.5
CEDD 75% MS 25%	4,796	7.2	24.0
MB 90%, MR 10% (baseline)	4,571	6.9	22.8
MS 75% MB 25%	5,947	8.9	29.74

SOURCE: Office of Technology Assessment.

cerns for development program contingencies. Production cost estimates confidence has been stated by Aerospace as about ± 25 percent. This production effect on the baseline cost estimate would be as follows:

Baseline (1,500 sensors)	$9.09 million
Low estimate	$6.82 million
Worst case estimate	$11.4 million

The effects of quantity and sensor mix are more profound. Sensor costs could vary from $5 million to $19.8 million (see table 53) for the baseline quantity of 1,500 sensors depending on the number mix of system deployed. Quantity variations would also proportionately impact program costs. High false alarm rates (greater than 0.05 percent) in fielded sensors would have tangible cost impacts in the cost of operations and in creating ill will.

Programmatic considerations.—The overriding uncertainty in the cost of the taggant program stems from the nature of the present early phase of program development. Program cost uncertainty is a profound problem during the development phase of most major hardware system programs. This is so even for programs where precedent-type data are available (e.g., aircraft, missiles, electronics). The taggant program has no direct precedent as such and analogous situations are limited. Historical data are therefore severely limited and slowly evolved as pilot testing progresses. Traditionally, as a program proceeds during development, new elements of cost are recognized that were poorly perceived at the onset of development. In addition, program directions change as engineering and scientific problems are uncovered, resulting in scope changes and potential for cost growth. Questions of scope, for instance, include program implementation levels which have been addressed in the cost synthesis section. As noted, cost estimates can vary by significant degrees depending on the program specifications. Related to the scope issue are the individual identification and detection taggant programs as separate entities. Pursuing either one of these objectives rather than proceeding jointly would have a significant impact on cost.

ADEQUACY OF CURRENT DATA

The taggant program cost estimates are based on a limited empirical data base and various analyses and assumptions. The situation is caused by the relatively early stage of the developmental program, the limited number of pilot tests conducted to date, and the limited sample of organizations surveyed (manufacturers, distributors, and users of explosives). The limitations in the data base and resultant assumptions have been underscored within the cost analyses section. Where assumptions were made, OTA has taken a conservative position in order to provide a reasonable cost estimate for the program options. This is important because cost growth normally shadows typical developmental efforts. Cost growth is predominately affected by redesign and program scope changes; cost-estimating error contributes to a lesser degree.

Further pilot testing and sensor development efforts are required in order to provide refined designs and requirements data for both manufacturing processes (e.g., detonating cord and blasting caps) and sensors, which are necessary to redevelop the cost estimates. Until this progress is made, further refinements in cost-estimate precision are not possible.

Additional survey samples of manufacturers, distributors, and explosives users would provide higher confidence in several of the cost element estimates and other cost impact areas.

SUGGESTED FURTHER RESEARCH

Additional cost analysis research would improve the ability to determine more accurately and at a finer level of resolution the cost impact of the taggant program. This research effort could take a number of avenues including

- development of a cost model
- development of an economic model
- application of design-to-cost principles for the sensor development, and
- special studies and analysis.

The OTA study effort on the costs of the taggant program was limited in time and resources. Various insights gained during this research indicate that further research in the above areas would contribute significantly to a better understanding of the multitude of cost and economic tradeoffs and effects which could guide the development of a taggant system. The model developments (cost and economic) would further this goal. Applications of formal design-to-cost principles to the development of sensors will further permit the production and implementation of cost-effective systems.

Other special studies and analyses would provide further value to the understanding of taggant program cost impact. Among these are

- cost/uncertainty probability analysis,
- price elasticity for black powder, smokeless powders, and cap-sensitive high explosives, etc.
- assessment of manufacturers' "joint end" costs and the related burden, and
- amplified cost and economic impact surveys of manufacturers, distributors, and users of explosives.

It must be clearly understood, however, that resolution of the basic program issues, such as level of implementation as well as resolution of technical efficacy, safety, and utility is necessary before it makes sense to attempt a more detailed cost analysis. The work reported in this chapter clearly indicates the order of magnitude of the cost impact that decisions concerning taggant legislation would have on the manufacturers, distributors, and users of explosives and gun powders.

Chapter VI

TAGGANT UTILITY REVIEW

Chapter VI.-TAGGANT UTILITY REVIEW

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Chapter VI

TAGGANT UTILITY REVIEW

INTRODUCTION

Bombings are a particularly heinous crime as they are normally indiscriminate in their choice of victims, often involve innocent people, and have the potential for producing large numbers of casualties and high property damage. Bombings are attractive to the perpetrator as bombs can be placed at the bomber's convenience and set to detonate at a time when the bomber is elsewhere. Bombings are a quite spectacular crime, easily drawing public attention when that is the perpetrator's purpose.

Bombings are particularly difficult crimes for law enforcement agencies to handle as the bomber is not usually near the scene of the crime, the physical evidence is destroyed or damaged by the detonation, and the materials necessary to fabricate even a quite catastrophic bomb are easily obtainable.

It is the purpose of this chapter to review the utility of both identification and detection taggants to law enforcement and security personnel. In order to assess the utility of taggants, it is first necessary to understand the magnitude of the bomber problem, including the types of bombers, the types of targets, the sources of explosives, and current measures to control and combat bombers. This information is reviewed in the next section. The utility of taggants is then discussed, together with possible responses by criminal bombers to a taggant program. The chapter concludes with a short discussion of the experience of selected foreign countries in the control of bombers.

In the analysis it is assumed that the taggants have been demonstrated as safe to add to explosive materials; that the identification taggants survive the detonation of tagged explosives and can be recovered at the scene of the crime, either directly or by laboratory separation of collected debris; and that sensors exist which detect the detection taggant vapor at a parts-per-trillion concentration in air with extremely low false alarms and with no requirement for special maintenance or skilled operators. These assumptions would have to be verified before a taggant program could be implemented.

The analysis is primarily qualitative. Data exist on the numbers and types of criminal bombings which take place, but it is difficult to analyze the data as it is not consistent from one data bank to another and information retrieval in any other than summary form is difficult. Characterization of types of perpetrators, or of motives, is available in only a limited number of bombings; even identification of the explosive filler is not available for a significant fraction of bombings.

No data exist that would allow a quantitative assessment of the numbers of bombers who would be deterred, arrested, or convicted as a result of a taggant program, or of the amount of property damage or casualties which would be averted by such a program. An analogy can be drawn between the utility of the present date-shift information code used on explosive cartridge cases and the utility of identification taggants in apprehending and convicting bombers, but the date-shift information data base is quite small. Similarly, an analogy can be made between the drop in hijackings that occurred after the introduction of antihijacking procedures and the potential reduction to be expected in the bombings of high-value and limited-access buildings protected by detection sensors. Such analogies are discussed in the text. The primary source of data on the current bombing threat, current means of combating that threat, and the utility of taggants to law enforcement personnel, however, comes from the opinion of law enforcement personnel in the field.

In-depth discussions were held with a broad cross section of law enforcement and security personnel, including personnel from the following agencies:

- domestic law enforcement and security personnel (New York City, San Mateo County, Calif., Dallas-Fort Worth Airport, Summit County, Ohio, Washington, D.C.);
- foreign law enforcement personnel (West Germany, England, Republic of Ireland, INTERPOL);
- Federal agencies (Federal Bureau of Investigation (FBI), Federal Aviation Administration (FAA), Bureau of Mines, Department of Transportation, Corps of Engineers, U.S. Army Criminal Investigation Division, U.S. Army Development and Research Command); and
- contractors (Management Science Associates (MSA) and Institute for Defense Analyses).

A number of discussions were also held on various subjects with the Bureau of Alcohol, Tobacco and Firearms (BATF), the agency charged with explosives control.

Unfortunately, it was not possible, given the time and money constraints of the OTA study, to meet with as many law enforcement personnel as would be desirable, particularly given the large variations in types of bombers, types of targets, and local laws and procedures in the various parts of the country. To obtain a larger sample of expert opinion, a questionnaire was sent to approximately 950 members of the International Association of Chiefs of Police (IACP), chosen at random from their directory. The IACP was chosen because of the OTA desire to obtain input from a broad cross section of the law enforcement community—geographically, functionally, and by size of community. The results of the in-depth interviews and questionnaire responses are integrated in the discussion in this chapter. A detailed discussion of the questionnaire is given as appendix F. Due to the small response rate (approximately 15 percent) the sample may be biased. However, the bias is probably toward those with knowledge of and interest in the subject. An additional possible bias was introduced by an error in the explanatory material accompanying the survey, which indicated that the identification taggant trace would identify the last legal purchaser of the explosives, rather than indicating that the trace would produce a list of last legal purchasers.

PROBLEM CHARACTERIZATION

Approximately 3,000 incidents are reported annually in the BATF *Explosives Incidents Report*. The incidents include accidents, threats, recovered explosives, and hoaxes, as well as actual explosive and incendiary bombings. The BATF report includes a breakdown by target type and explosive filler used, but little information on the various types of perpetra ties. The FBI compiles similar bombing statistics at its National Bomb Data Center, which are published quarterly and summarized annually. The bombings are committed by a wide range of perpetrators, who differ in their skills, resources, motivations, and types of targets attacked. Current security measures at most explosive manufacturers, distributors, and users are sufficient to dissuade casual outside theft but cannot readily protect against thefts that are committed by or aided by employees, or against a determined outside attempt to steal explosives. Protection of some high-value potential targets against bomber threats is currently adequate, but some targets are essentially unprotected against a serious bombing attempt. Finally, current law enforcement efforts to control criminal bombings are not very effective. These topics are discussed directly below.

The Bombing Threat

Both the FBI and BATF maintain national bombing data information centers which collect statistics on bombings and other explosive incidents. The data are not consistent between the two centers, however, and many bombings are not reported to either center. The formatting of the data, and the lack of updating procedures, make accurate analyses difficult.

The BATF 1978 *Explosives Incidents Report* includes over 3,000 incidents for both 1977 and 1978. The incidents include accidents, threats, seized and recovered explosives, and hoaxes as well as actual explosive and incendiary bombings. Of these incidents, 1,377 represented explosive detonations, accidental detonations by bombers, or recovered bombs which failed to detonate in 1977, with 1,250 the corresponding number for 1978. At least 253 of these in 1977 and 767 in 1978 represent actual detonations of explosive bombs against accidental targets (mailbox and open-area bombings are not included).

During 1977 at least 38 people were killed and 180 wounded by explosive and incendiary bombs, while the numbers in 1978 were 23 and 165, respectively. Due to the way in which estimates of property damage are made in the BATF data and the lack of updating, only the crudest property damage estimates can be made. There was at least $10 million in direct property damage due to explosive and incendiary bombs in 1977 and at least $17 million in 1978. Thirty-two of the thirty-eight reported deaths in 1977 and twenty of the twenty-three reported in 1978 were from bombings against vehicles, residences, and commercial establishments. Similarly, about 80 percent of the injuries from bombing of known targets in 1977 and 70 percent in 1978 were caused by bombings of those three types of targets.

The FBI data, as indicated above, are somewhat different, both in numbers of incidents reported and in the breakout of categories. In 1977, for instance, FBI data show 867 actual explosive bombings and 319 attempted bombings. Similarly, the number of people reported killed that year from both explosive and incendiary bombings was 22, while 162 were reported injured. In 1978 there were 768 explosive bombings and 105 attempted explosive bombings. The pertinent 1977 and 1978 BATF and FBI statistics are summarized in table 54.

Table 54.—Minimum Bombing Incidents Statistics Summary

	BATF		FBI	
Item	1977	1978	1977	1978
Explosive detonations, number	1,037	898	867	768
Undetonated explosive bombs, number	299	287	319	105
Incendiary bombings, number	334	448	248	349
Unignited incendiary bombs, number	6	71	55	78
Criminal explosive thefts, number	21	87	—	—
Property damage from bombings, millions of dollars	$10	$17	$9	$9
Injuries	180	165	162	135
People killed by bombings	38	23	22	18

[illegible]

SOURCE: BATF 1978 *Explosives Incidents Report*; FBI *Uniform Crime Report*. [illegible]

An effort was made to resolve the differences in statistics compiled by FBI and BATF according to the Explosives Enforcement Division of BATF.

- There is no Federal statute or law on the books requiring local police officials to report bombing incidents to either BATF or the FBI.
- Cooperation at the local level has led to an informal procedure on the part of local police to report a bombing incident to either BATF or FBI who in turn will normally notify each other. (There are obviously some breakdowns in this procedure.)
- There is a statute giving BATF the "right of inspection" at the site of any explosion; therefore, whether BATF receives word of a bombing from the local police or whether a local special agent reads of it in the local paper, BATF can by law check it out.
- BATF requires each agent to report all bombing incidents to the explosives data center in Washington irrespective of the theoretical importance, damage, casualties, or jurisdiction since, among other uses, these data are used by the Secret Service in arranging security for the President when he is traveling.
- There is a question of jurisdiction with reference to investigations. A memorandum of understanding exists between BATF and the FBI. Generally, the FBI covers terrorist acts, attacks on airlines, attacks involving unions, college campus buildings, and Federal buildings other than Treasury and Postal buildings. BATF has primary jurisdiction over criminal bombings related to interstate commerce, firearms violations, and Treasury buildings. Either the FBI or BATF may respond to requests for aid from other jurisdictions. Conflicts are settled by mutual agreement.
- The normally higher number of incidents annually in BATF reports is a direct result of the above.

It is of considerable interest to know whether the statistics for 1977 and 1978 are characteristic of the recent past or if trends in criminal bombings are apparent. Table 55 shows the bombing trend since 1972 from the FBI data. While the BATF numbers differ, the rough trends are similar. Figure 22 shows the trends graphically, with the total number of incidents depicted in figure 22a, property damage in 22b, injuries in 22c, and deaths in 22d. The total incident numbers in figure 22a include both successful bombings and attempts; the property damage and casualty figures may include incendiary bombings as well as explosive bombings. No long-term trend is detectable from the data, although an unusually high number of incidents and casualties occurred in 1975. This increase was primarily due to three incidents:

1. On January 24 a bombing at the Fraunces Tavern in New York City killed 4 people, injured 53 others, and did extensive property damage. Responsibility for the bombing has been claimed by FALN, the Puerto Rican separatist terrorists.
2. A bomb detonated in the baggage claim area at La Guardia Airport on December 29, killing 11 people with 70 additional serious injuries. No positive identification of the exact type of explosives used has been made for this incident and no attribution has been made.
3. A bomb detonated at a sponge factory in Shelton, Conn., in March 1975, killing

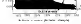
Table 55.—Explosive & Bombing Incident Trends, 1972-78

Year	Total actual and attempted explosive bombings	Actual	Attempted	Total actual and attempted incendiary bombings	Actual	Attempted	Property damage (dollar value)	Personal injury	Death
1972	951	714	237	911	791	120	$ 7,992,000	76	25
1973	995	742	253	960	787	173	7,262,000	187	22
1974	1,129	893	236	915	758	157	9,852,000	207	24
1975	1,330	[illegible]	258	748	613	135	27,0[illegible],000	326	69a
1976	1,040	852	188	530	405	125	[illegible],293,000	212	50
1977	983	867	116	333	248	85	8,543,000	162	22
1978	873	768	105	424	349	75	9,161,000	135	18

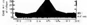
aIncludes two major bombings/incidents resulting in unusually high personal injuries and death and substantial damage.

SOURCE: FBI Uniform Crime Reports Bomb Summary, 1978.

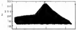
Figure 22.—Annual Bombing Statistics, 1972-77



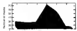
a. Bombing incidents (includes attempts)



b. Property damage (includes incendiary bombings)



c. Personal injury (includes incendiary bombings)



d. Deaths (includes incendiary bombings)

SOURCE: Drawn by OTA from FBI data.

three people and injuring several others. No attribution has been made for this incident.

Using FBI and BATF data the trend of both total bombing incidents and catastrophic incidents was analyzed by MSA for the 5-year period from 1972 through 1976. The data show no significant change in incidents over that period, although 1975 and 1976 had significantly higher injuries and deaths. In contrast to inferences based on past statistics, many experts believe a significant increase in bombings, particularly catastrophic bombings, can be expected over the next few years. It should be noted that a single incident involving an aircraft exploding in flight could produce more deaths than have occurred in the United States from bombings during this decade. Such incidents have occurred in foreign countries and a near miss occurred recently in New York. On March 25, 1979, a TWA plane bound from New York to Los Angeles was delayed. A bomb planted in the checked baggage exploded while being transported to the aircraft on the baggage truck. If the aircraft had taken off on time the bomb might have caused the deaths of most or all of the 144 people aboard.

Explosives Used in Bombs

Data on the types of fillers used in bombs are also not consistent between FBI and BATF data banks. It is instructive to look at two BATF data sources, however, as shown in table 56. The second column represents 1978 data for the fillers identified in the field for all explosive bombs that were detonated, bombs recovered undetonated, and criminal accidents. The first column represents 1978 data for only those fillers that were identified in the laboratory from postdetonation analysis. In both cases, black and smokeless powders and cap-sensitive high explosives all occur with high frequency. Table 57 shows a breakout of the estimated number of significant bombing incidents, deaths, injuries, and property damage occurring during 1978 by explosive material filler. The average of the two frequencies columns shown in table 56 was used for the table 57 estimates. (See app. F for the derivation of

Table 56.—Identified Explosive Fillers Used in Bombs

	Lab identified fillers 1978	All identified fillers 1978	Average
Black powder	13%	25%	19%
Smokeless powder	16	19	17.5
Military	2	7	4.5
Cap sensitive	32	30	31
Blasting agents	—		.5
Chemicals	—		
Others	36	2	29

See app. F for derivation of these numbers.
SOURCE: BATF data.

Table 57.—Bombing Casualties and Damage in 1978 by Type of Bomb

Filler material	Number of bombings against substantiated targets	Deaths	Injuries	Property damage $ millions
All fillers	1,286	23	195	$17.2
Incendiary	428	3	73	3.7
Black powder	140	4	19	.2
Smokeless powder	152	3	23	.2
Military explosives	39	6	7	—
Cap-sensitive	271	7	26	3.5
Other		3	41	2.4
Unknown		0	37	7.4
Total for those fillers which would be directly tagged	571	4	61	3.7

aAggregated by type due to lack of data.
bCap-sensitive explosives, black powder, and smokeless powder would be tagged.
SOURCE: BATF data. See app. F-III for derivation of these figures.

these numbers.) The table shows that a large percentage of the total bombings, deaths, and casualties is caused by black powder, by smokeless powder, and by cap-sensitive high explosives.

Types of Targets Bombed

The types of targets that attract criminal bombers range from attacks on mailboxes and outhouses by vandals and pranksters to attacks on aircraft by terrorists. The targets most frequently attacked on a year-to-year basis are private residences, commercial facilities (usually small operations), and vehicles. Table 58 is taken from the BATF 1978 Explosives Incidents Report. It shows the total number of actual bombings (both explosive and incendiary) for the years 1977 and 1978, the bombing breakout by target type, the number killed and injured, and the estimated property damage all by target type. The FBI data are somewhat different but show the same trends in that the majority of bombings, property damage, and casualties occur at residences, at commercial locations, and in vehicles. In table 59 these data are rearranged to explicitly show that most of the bombings and casualties would occur at targets that are not likely to be protected by detection sensors. It is extremely unlikely that such sensors would be placed in private residences or in vehicles; most commercial establishments would also not have sensors. If the assumption is made that all of the incidents that happened at commercial facilities occurred at facilities unlikely to be protected by sensors, then 79 percent of the incidents, 88 percent of the injuries, and 94 percent of the deaths from actual explosive and incendiary bombings which happened in 1977 and 1978 occurred at places unlikely to be protected by detection taggant sensors.

Data are not available that would allow separation of the explosive and incendiary bombing statistics. It is likely that a large percentage of the targets of explosive bombings would be of the type protected by a detection sensor, but probably not a large percentage.

Characteristics of Criminal Bombers

Criminal bombings are committed by a wide range of perpetrators, including both individuals and groups. While it is always difficult to place a heterogeneous population into well-defined categories with well-defined characteristics, it is helpful to group criminal bombers into four categories: terrorists, common criminals, mentally disturbed, and vandals and experimenters. These groups vary greatly in motivation, skill, training, resources, and ability to respond to a changing enforcement environment. It is also difficult to determine which group is responsible for a bombing, although credit is sometimes claimed, particularly by certain terrorist groups. Of the bombings reported in the BATF 1978 *Explosives Incidents*

Table 58.—Bombings by Specific Targets for 1977-78 (actual detonations or ignitions)

Type target	Total incidents 1977	Total incidents 1978	No. killed 1977	No. killed 1978	No. injured 1977	No. injured 1978	Property damage[a] 1977	Property damage[a] 1978
Residential	332	294	17	7	88	57	$1,022.3	$2,092.2
Commercial	367	378	7	6	43	48	[illegible]	6,777.7
Agricultural	7					—		2
Police facility/vehicle	19	2	—	—	—	—	5	70.4
Educational	105	97	—	—	3	5	45.	532.5
Government (local)	24	8	—			4	745.9	76.1
Government (Federal)	29	22	—	—	8		2.4	8.8
Military installations	4	3	—	—	—		—	0.0
Utilities	51	57	1	—		2	628.0	727.7
Banks	22	18	—	—	—	—	225.2	49.5
Vehicles	218	252	11	7	34	25	343.3	2,111.4
Open areas	36	40		2	9	10	.5	4.2
Mailboxes	48	60	—	—		2	26.8	2.
Other	91	32	—	—	1	27	7,276.8	866.9
Unknown[b]	34	2	—	—	1	2	22.0	7.0
Total	1,357	1,489	38	23	[illegible]	65	[illegible]	$17,212.1

[a] Property damage figures are in thousands and are estimates.

[b] Includes property/incidents where the type of target was either unknown or not reported.

SOURCE: FBI 1978 Bomb Summary Report.

Table 60.—Percent of Bombing Targets That Would Be Protected by a Detection Sensor

	Total bombings		Injuries		Deaths	
Average number of bombings of known or potential targets[a]	1,175		98		29	
Bombings of residences, vehicles	557	(47%)	56	(57%)	21	(72%)
Bombings of commercial establishments	371	(32%)	47	(31%)		(22%)
Total unlikely to have sensors	928	(79%)	150	(88%)	2	(94%)

[a] Includes both incendiary and explosive bombings for 1977 and 1978.

[b] Vehicles and mailboxes are excluded from this total.

SOURCE: BATF data.

Apparent motive was established for only 23 percent of the bombings in 1977 and only 29 percent in 1978. Keeping in mind the above reservations, it is nonetheless useful to examine the characteristics of the various groups, which are summarized in table 61 and briefly described below.

Terrorists

The terrorist groups active in the United States vary widely in ability, resources, training, and adaptability. They share the common characteristics, however, of high motivation, action as a part of a group, and a continuing involvement in catastrophic illegal activities against society. These characteristics make the terrorist particularly dangerous to society and a particularly appropriate target for anti-bombing controls. Terrorists can be roughly divided into political, reactionary, and separatist groups. Political groups such as the Weather Underground are primarily interested in attracting attention to and sympathy with their cause. For that reason they engage in spectacular events such as bombings but generally attempt to avoid or limit injury and death resulting from their bombings. Political terrorists often have considerable resources available to them due to a significant number of people who support their aims if not necessarily their means. The leadership of most of these groups are of above-average intelligence and have either had specialized training or have studied extensively in terrorist activities. They are thus able to adapt to a changing environment, although the range of responses available to them may be limited by their political aims. They may lack mechanical skills, however, and be more likely to be involved in accidental ex

Table 60.—Attributes of Criminal Bomber Groups

Perpetrator	Experience and training	Resources	Motivation	Individual or group	Reaction capability	Frequency
Criminal						
Unsophisticated	L	L	M		M	Multi
Sophisticated	H	M	H		H	Multi
Terrorist						
Political	M-H	M-H	M-H	G	M-H	Multi
Separatist	M-H	H	H	G	H	Multi
Reactionary	L	L	H	G	L-M	Multi
Mentally disturbed						
Disenchanted	L	L	L-M		L	Single
Vengeful	L	L	M-H		L-M	Single
Pathological	L-M	L	H		L-M	Varies
Other						
Vandals	L	L	L-M		L	Single
Experimenter	M	L	L-M		L-M	Single

L=Low; M=Moderate; H=High; I=Individual; G=Group
SOURCE: Office of Technology Assessment.

plosions either while fabricating bombs or while placing them. Political terrorists have become less visible in the United States in recent years.

Separatist groups, such as FALN, generally hope to gain their aim by generating a reaction to their activities rather than sympathy for their aims. They are therefore generally less concerned with public revulsion to bombings that cause substantial injury and deaths. Separatist groups have been credited with more than 25 percent of catastrophic bombings—those resulting in major property damage, injuries and deaths. The resources of domestic separatists vary from group to group but are generally less than for comparable groups of political terrorists, as only a fraction of the population represents even potential supporters. As an example, few people outside of the Yugoslavian exile community care whether or not the Croatians achieve separation from the Yugoslavian federation; on the other hand, a group like the Weather Underground that seeks to exploit discontent with the U.S. Government could seek support from a larger population. Separatist groups are often critically dependent on a small cadre of leaders; loss or incapacitation of these leaders may shatter the group or considerably reduce their effectiveness. As an example, FALN in New York lost their bombmaker over a year ago and have not committed any bombings in New York since that time. Their ability to react to a changing control environment is less than the political terrorist groups, due to more limited resources. If the goal of the separatist group is viewed with sympathy by a large part of the population, as is the case in Northern Ireland, then the group can attract resources, attract recruits, and perfect skills. If, on the other hand, the population is either not in sympathy with the separatists or is not directly affected by the cause of the separatists (as is the case of the Croatians in the United States or the South Moluccans in the Netherlands), then the group will not be able to attract resources or otherwise grow.

Reactionary groups, such as the Ku Klux Klan and the American Nazi Party, would appear to share some of the characteristics of the political terrorists but generally do not possess the same levels of training, motivation, and resources, and are not as capable of reacting effectively to a changing control environment. They also differ in that their bombings are usually directly targeted at the individual or group they intend to influence, rather than simply at a spectacular target. Generally, their purpose is intimidation; thus, fairly small contained bombs are used. Even when murder or injury is desired, the results are usually confined to the directly targeted individual. While the political terrorists are generally younger and well educated; the reactionary terrorists tend to be less well educated and somewhat older.

Terrorists, as a group, have been responsible for approximately 12 percent of those bombing incidents in the past 8 years for which the FBI attributed a motive.

Common Criminals

Criminals range from the petty operator who utilizes a bomb for extortion to the professional bombers of organized crime. The petty operator is generally poorly trained, not very motivated, has limited resources, and cannot readily adapt to a changing enforcement environment. The only major characteristics he shares with the professional bomber are that his targets are generally individuals or small commercial establishments unlikely to be protected by a detection taggant sensor, and that he generally works alone or as part of a small group. The petty operator normally engages in repeated bombings over a number of years.

The professional bomber is highly trained and motivated and generally has considerable resources available to him, either directly or through his "employer." While the professional generally works alone, he may be affiliated with a larger criminal structure such as the organized crime network in the United States. His target may range from bombs planted as a result of labor problems to murder-for-hire "hits." The professional bomber and the more sophisticated terrorists share many characteristics and are the most difficult to control or contain.

Criminals as a group are responsible for approximately 11 percent of bombing incidents. Most incidents are limited to specific targets and do not generally cause substantial injury or death to innocent bystanders.

Mentally Disturbed

The category of mentally disturbed includes psychopaths, those seeking revenge for a real or imagined wrong, and those who may be temporarily disenchanted with a particular situation. Many of the individuals who become terrorists or criminals could fall into this broad category; the term is limited here to the disturbed persons who act alone and do not act for profit.

The mentally disturbed bomber also differs from terrorists and criminals in that he generally does not engage in multiple bombings, although exceptions such as the Los Angeles "alphabet bomber" certainly exist. He generally is poorly trained, has limited resources, and acts alone. He is often highly motivated, but perhaps only for short periods of time in direct response to some stimulus. He is extremely limited in his ability to respond to changing control situations, either through lack of care of consequences or belief in his invincibility. As his motives are hard to identify, it is difficult to predict his target.

The mentally disturbed account for approximately 38 percent of all bombing incidents that can be attributed to a specific type of perpetrator.

Vandals and Experimenters

Vandals and experimenters share the characteristics of poor training, limited motivation, and limited resources. They generally work alone or in small groups and do not generally intend to harm people or cause extensive damage. Their targets are often of little value, such as mailboxes or outhouses, but some acts of vandalism can cause extensive damage to buildings such as schools. While accounting for 39 percent of the reported bombing incidents, they are responsible for little damage and few casualties.

The primary danger from this group is that a harmless prank may accidently turn into a major bombing with subsequent significant property loss and casualties. There is also the danger that experimenters will learn their craft and "graduate" to a more dangerous category of criminal bomber.

In summary, table 61 shows the approximate number of significant explosive bombings (excluding mailboxes and detonations in the open) that would be attributable to each type

Table 61.—Estimated Number of Significant Bombings by Group of Perpetrators (average of years 1974-78)

Perpetrator group	Estimated number of bombings
Terrorists	107
Criminals	98
Mentally disturbed	340
Vandals and experimenters	340

SOURCE: FBI data. See app. F for a definition of these figures.

of perpetrator, if the same relative distribution by perpetrator held for unattributed bombings as for attributed ones. To obtain these estimates, OTA averaged FBI data from the 5 years 1974-78 (no 1979 data is yet available). Year-to-year numbers vary due to changes in the FBI categories and method for allocating bombings by motive. (See app. F for more detail.)

No detailed data is available concerning the number of deaths and injuries caused by the various bomber groups. However, almost 48 percent of catastrophic bombings (those with casualties or serious property damage) are attributed to separatist terrorists and the more professional criminals.

Sources of Explosives

The explosives used in criminal bombings can come from a variety of sources including:

- legal purchase,
- illegal purchase,
- theft,
- importation from abroad,
- homemade, and
- theft of some components, fabrication of others.

At present, a determination of the source of explosives can rarely be made except in the case of bombs that have been recovered undetonated. The date-shift code information on the cartridge label allows the source of the recovered explosives to be traced. Such traces can theoretically locate the source of essentially all cap-sensitive high explosives recovered in their original cartridges; however, investigative effort is necessary to determine which of the last legal purchasers on the list is the source of the explosives. Such an effort would be expended if the recovered bomb had the potential to cause catastrophic damage, if the target was an important one, or if the pattern of the attempted bombing indicates that useful intelligence information would be gathered by the trace. Devices recovered undetonated which were small in size or which were to be used against relatively unimportant targets may well never be reported to the ATF network.

While it is impossible to determine precisely the source of explosives used in most criminal bombings, analysis of the existing data does indicate some trends. Examining table 59, it appears that homemade explosives are used very infrequently in criminal bombings in the United States, although they account for up to 85 to 90 percent of the explosives used in countries such as West Germany and England, where commercial explosives are rigorously controlled. There also appears to be little use of explosives imported from abroad, a judgment supported by discussions with various law enforcement agencies. Both of these sources could become more important, however, if a taggant program were legislated.

Illegal purchases are primarily of stolen explosives, discussed below. That leaves legal purchases and theft as the primary current sources of explosives.

Explosive materials can be purchased legally in each State; the requirements vary from State to State, and they vary for different explosive materials. In every State, gunpowder can be purchased legally. Identification may or may not be required for smokeless powders and is required for black powder. In some States, cap-sensitive high explosives can be purchased simply by showing identification and filling out a form. In others the explosives can only be legally sold to people with State or Federal licenses.

A general rule-of-thumb expressed by most law enforcement personnel was that criminal bombers will use the most easily available source. If explosives can be purchased legally, the bombers will do so. The Weather Underground apparently purchased much of their explosives legally in New Hampshire. If explosives are easy to steal then stolen explosives will be used. Explosives are more prevalent and easier to steal in the western States; a large theft from Colorado, for instance, furnished the explosives for a large number of bombings in the Eastern States.

BATF keeps track of stolen explosives as well as explosives seized, recovered, or found. The data for 1977 and 1978 are summarized in table 62. While no firm conclusions about outstanding amounts of explosives can be made on the basis of the data, several trends are apparent.

- Little gunpowder is stolen. As gunpowders are easily purchased, there is little need for theft.
- Large amounts of blasting agents are stolen and recovered each year. According to table 56, however, little of it is used in criminal bombings.
- More military explosives seem to be recovered than stolen. This may be due to the inclusion of "souvenirs" as recovered explosives or to the reluctance of the military to report thefts. At any rate, the amounts stolen are small. Much of the military explosives used by criminal bombers is material acquired some years ago. For instance, the Cuban exile terrorist groups such as Omega 7 still primarily use C-4 given to them by the Central Intelligence Agency at the time of the Bay of Pigs invasion.
- The amount of cap-sensitive explosives stolen and recovered appears in rough balance. Some of the recovered explosives, however, are old abandoned explosives found in old mines and other places. A significant net amount is probably available and used for criminal bombings.
- A large net number of blasting caps appears to be stolen each year and to be available for use in criminal bombings. This is not surprising as caps are generally not as well secured as main charge explosives. If a taggant program is adopted, security of detonators will require upgrading, as detonators are generally needed to initiate explosives and the fabrication of detonators is a much more difficult and dangerous job than fabrication of the main explosive charge.

An additional analysis can be made of the frequency with which explosives are stolen on a State-by-State basis and compared to the frequency of criminal bombings. A high correlation appears between the number of thefts and number of bombings. An even higher correlation appears when the thefts from nearby States are included in the analysis. As an example, both California and New York have more stringent regulations controlling the use and storage of explosives than nearby States such as New Jersey and Washington. Law enforcement officials feel that many of the incidents in New York and California use explosives stolen in New Jersey and Washington.

Table 62.—Stolen and Recovered Explosive Summary

Type	Amount stolen 1977	Amount stolen 1978	Amount recovered 1977	Amount recovered 1978
Blasting agents pounds	20,884	42,172	21 290	20 022
Black powder pounds	45	379	277	723
Smokeless powder pounds	5	183	16	1,261
Boosters pounds	2 177	9 528	2 504	362
Military explosives pounds	48	141	940	761
Cap-sensitive high explosives pounds	36 457	44,281	43,738	41,617
Primer units	1 300	4 333	2 783	344
Blasting caps units	[illegible]	86 110	[illegible]	44 456
Det cord/safety fuse/igniter cord feet	153,224	[illegible]	84 954	[illegible]
Total explosives pounds	[illegible]	111,287	[illegible]	74,966
Blasting caps units	[illegible]	86 614	40 710	44 458
Det cord/safety fuse/igniter cord feet	160 224	183 194	84 954	[illegible]

SOURCE: BATF 1978 Explosives Incidents Report.

Current Security Measures

Sources of Explosives

Current methods of securing explosives vary somewhat from State to State; different types of explosives are also secured in different ways. In general, all cap-sensitive high explosives, including boosters and detonating cord, must be stored in BATF-approved magazines. The magazines require hardened locks and lock-covers to protect the lock from direct access by hacksaws or from attempts to shoot off the lock. Detonators must be stored separately in magazines that are not as well protected from theft as the high explosive magazines. Blasting agents are not as well regulated; bulk ANFO is often stored in large hoppers for direct loading into trucks. Gunpowders are stored in BATF-approved magazines at least at the manufacturer and distributor levels. At the retail sales level, however, gunpowders are just stacked on the shelves.

The above provisions are for permanent storage; some States allow overnight storage of explosives in temporary magazines, or least one manufacturer keeps less than full-lot amounts of detonators in the detonator assembly area overnight.

The purpose of BATF and other regulations on the storage of explosives is primarily to protect against surreptitious or casual theft by outsiders, in much the same way that locking your car door protects the car from theft. The magazines, however, are fairly flimsy, often simply a corrugated frame building with additional plywood or plank walls. Entry can still be gained by cutting or prying off the locks, forcing entry through the door, a window, the roof, or a vent, or by help from an employee. Table 63, from the BATF 1978 Explosives Incidents Report, tabulates the methods used to gain entry to explosives. An average of 48 percent of known entries were by removing the lock; another 19 percent were by forcing entry through the door, wall, or vent; while almost 9 percent involved the use of a key or other inside help.

Some magazines are well-protected by their placement in a facility or by guards. At the Bingham Copper Mine, for instance, the magazine is placed within the interior of the property of the large open pit mine. The mine has a limited number of access points, controlled by guards. As the mine is operated three shifts a day, 7 days a week, it would be difficult for anyone to gain illegal access to the magazine area. A similar situation prevails for at least one manufacturer. The entire property is fenced with cyclone fencing, topped by barbed wire. Inside the perimeter, and placed strategically throughout the complex, is a microwave break-circuit alarm system. These facilities are in sharp contrast to others in which the magazines are located in areas remote from other operations and accessible by nearby roads.

Table 63.—Explosives Thefts by Method of Entry—Number of Incidents and Percentages in 1977-78

Entry method	Number 1977	Number 1978	Percentage 1977	Percentage 1978
Locks cut	59	71	31.1	28.5
Locks pried	30	51	15.8	20.5
Door pried	10	9	5.3	3.6
Key	14	22	7.4	8.8
Window entry	7	3	3.7	1.2
Inside help	3	1	1.6	
Wall entry	10	15	5.3	6.1
Ramming	2	1	1.0	.4
Roof entry	7	3	3.7	1.2
Door hinges		2	.5	.8
Floor entry	6			.4
Vent entry		3	.5	1.2
Other	40	80	21.1	32.1
Unknown	137	113	—	—
Total	327	362	100	100

aThese percentages do not include 137 unknown method incidents for 1977 and the 113 incidents for 1978.

The figure reflects those incidents where the entry method could not be placed in the above categories.

SOURCE: BATF 1978 Explosives Incidents Report.

Security of explosives on military reservations is stricter, with magazines within a fenced area. Security lighting is provided; the magazines are either directly guarded or protected by an alarm which would bring a response within 15 minutes; security patrol inspections are held at frequent intervals; and access is only through secured access roads.

At present, neither commercial nor military installations can guard against theft by insiders. While the theft of some lots would be quickly discovered by inventory procedures. It would be difficult to detect the theft of small amounts of explosives, whether by military troops or by a miner daily placing a couple of sticks of dynamite in his lunch pail.

Transportation of explosives is another potential point of theft. The primary purpose of regulations concerning the transportation of explosives is to protect those people who live along the route being traversed. For that reason trucks are clearly marked when they carry explosives. Commercial explosives are often transported by a single driver; military explosives normally have two drivers. In neither case is the driver normally armed.

Potential Targets

A previous section discussed the wide variety of targets attacked by criminal bombers. The security measures vary widely for each type in response to the perceived probability of attack and the perceived consequence of such a bombing. Table 58 indicates that almost half of the bombing incidents (and 50 percent of bombing casualties) result from attacks on private residences and vehicles. Security of these targets is almost nonexistent, unless the individual believes he is likely to be attacked; except in certain cases such as Government officials or witnesses, it is unlikely that law enforcement officials play much of a security role with regard to these targets.

Another 32 percent of the incidents and 35 percent of the casualties occur in commercial establishments. Most of these establishments have no security means at present and it is unlikely that the development of detection taggants and sensors would significantly change that situation. Some large office buildings with controlled access have provisions for checking people as they enter and leave the building and, in fact, institute checks in all work hours. Given a sufficiently severe bombing threat, it would be possible to protect the target facilities by a detection sensor, but the difficulties involved, the large number of facilities, and the cost of operators and equipment probably preclude such deployment.

Government buildings, banks, police stations, and military establishments account for less than 10 percent of bombing incidents and just over 3 percent of casualties. Most of these targets have controlled access and maintain some sort of guards. In times of increased bombing threats, as happened in the late 1960's and early 1970's, many of these facilities instituted checks of incoming people and packages. A similar situation exists with respect to high-value manufacturing facilities, utilities, and high-value complexes within educational facilities such as computer centers. Many of these facilities now require inspection of any parcels (including briefcases and purses) brought into the facility, as well as identification of people entering. Detection sensors could be easily installed in each of these facilities given sufficient threat.

Airports and aircraft represent another major class of potential targets. While attacks on airports and aircraft represent well under 1 percent of incidents, the catastrophic consequences of an aircraft bombing make it an attractive potential target for criminal bombers and the subject of much current security effort.

Current large aircraft cost in the neighborhood of $20 million to $50 million each and carry several hundred passengers. A single aircraft bombing could therefore cause more property damage and more deaths than the sum of all domestic bombings this decade. Table 64 lists the explosions that have occurred aboard U.S. aircraft from 1949 through 1978. Table 65 lists the location of the explosive devices for the 19 U.S. aircraft listed in table 64 and compares the location with the 63 aircraft bombings worldwide in that time period. Table 66 lists the 26 incidents between 1972 and 1978 in which explosive or incendiary devices were found at U.S. airports. All of the tables are from FAA report FAA-RD-77-28. The tables show that no bomb has caused casualties on a domestic flight since 1962. In fact, since 1962 all but one of the casualties and all deaths at U.S. airports or on U.S. domestic flights were caused by bombs placed in lockers.

Table 54.—Explosions Aboard U.S. Aircraft

Date	Carrier	Aircraft	Aircraft location	Bomb location	Outcome	Device
11/1/55	UAL	DC-6B	11 minutes after TO	Baggage	Airplane disintegrated—44 killed	Dynamite
7/25/57	WA	CV-240	47 minutes after TO	Lavatory	Passenger thrown out of lavatory—hole in aircraft side; plane landed successfully	Dynamite
1/6/60	NA	DC-6B	104 minutes after TO	Under seat passenger compartment	34 killed; airplane disintegrated	Dynamite, dry cells
5/22/62	CO	707	39,000 ft	Towel container in rear lavatory	Tail blown off—45 killed	Dynamite
11/12/67	AA	727	102 minutes after TO	Rear baggage compartment	3 bags destroyed; aircraft saved	Black powder (?)
11/19/68	CO	707	24,000 ft	Lavatory	Fire and explosion in lavatory extinguished by crew; plane landed safely	—
8/29/69	TW	707	Ground after hijack (Damascus, Syria)	Explosives thrown in cockpit after evacuation	No casualties from explosives	Incendiary & cockpit explosive
9/7/70	PA	747	Ground after hijack (Cairo, Egypt)	—	Demolished after evacuation	—
9/12/70	TW	707	Ground after hijack (Dawson Field, Jordan)	—	Demolished after evacuation	—
2/28/71	—	Turbo Comdr	In hangar	Seat in cabin	Aircraft destroyed, hangar damaged; no casualties	—
3/8/72	TW	707	Parked on ground	Cockpit	No casualties (plane empty)	C-4
8/2/73	—	Navion	Parked on ground	Engine manifold	Not known	
12/17/73	PA	707	On ground, Rome	Attack while loading	Fire damage; 30 killed, many injured	White phosphorus grenades
8/26/74	TW	707	On ground, Rome	Aft baggage compartment	Fire confined to local area; no casualties	C-4
9/8/74	TW	707	Over Ionian Sea	Aft baggage compartment	High-order explosion; 88 killed; aircraft lost	—
2/3/75	PA	747	In flight, Burma	Lavatory (suicidal passenger set fire)	Extinguished by crew; minimum damage	Paint and butane
12/9/75	—	Alouette helicopter	On ground	Near fuel tank	$12,000 damage to aircraft	Blasting caps
7/2/76	EA	Electra	Parked next to fence	External, near right landing gear	Explosion and fire destroyed main fuselage	Dynamite (9-10 sticks)
7/8/76	—	Helicopter	On ground	External, under tail	Extensive damage	Dynamite

SOURCE: FAA Civil Aviation Security Service.

Table 55.—Location of Explosions Aboard Aircraft, 1949-76

	Worldwide		U.S. aircraft	
Location of explosion	Number	Percent	Number	Percent
Stowed	11	21		21
Baggage	(6)			
Cargo or freight	(5)			
Ground attack	5	9	4	21
External attachment	7	13	3	16
Passenger or crew compartment		52		42
Lavatory				
Passenger compartment	(—)		(2)	
Cockpit	(4)			
Unknown	5	9		0
Total	55	100	19	100

SOURCE: Data supplied by FAA Civil Aviation Security Service.

Current airport security is based on an attempt to separate the areas of public access from the secure air operations areas. Figure 23—from FAA report FAA-RD-77-2[illegible]—shows a detailed schematic of the flow of people and materials into the airport area.

It is possible that bombs could be introduced through the mail, freight, or courier services or food services as well as from checked baggage, or could be carried on by aircraft flight or service personnel or by passengers. Current security procedures assume that personnel screening procedures will be sufficient to eliminate a serious threat from airport or aircraft personnel and that air freight and mail service would not allow a criminal bomber to be sure his bomb would be aboard a particular aircraft. Current aircraft security procedures therefore concentrate on passengers' carry-on baggage and checked baggage. Air courier services in which a small

Table 21.—Explosions and Devices Found at U.S. Airports, 1972-75

Date	Airport	Location	Effects	Comment	Device
3/7/72	Kennedy	Cockpit of TWA 707	No explosion	Detected by dog	C-4
3/8/72	Seattle	Baggage compartment (UAL flight)	No explosion	Extortion attempt; bus stopped	Gelatin dynamite, a second case, blasting caps
[illegible]/72	Denver	Attache case carried by individual	No explosion	Individual stated intent to blow up plane	8 sticks of dynamite
3/24/72	San Carlos, Calif.	Hanging from belly of helicopter	Hole in ground at remote location	Removed by police	3 sticks of dynamite, timer and detonators
12/[illegible]/72	Grand Rapids, Mich.	Paper towel container in terminal	No explosion	Device extinguished after emitting smoke	—
[illegible]/73	Austin	Concession area	Moderate damage	—	Incendiary (gasoline)
5/20/73	Los Angeles	On runway during approach of Continental Airlines plane	None	Thrown by individual on field	Molotov cocktail
5/29/73	Milwaukee	Locker	1 injury—moderate damage	Extortion attempt	—
6/9/73	Los Angeles	Locker	Did not detonate	Extortion attempt/located by dogs	—
11/30/73	Nashville	Locker	Did not detonate	Extortion attempt	Smokeless powder, timer initiate
2/[illegible]/74	Kennedy	Locker	3 injured—moderate damage	—	
7/2/74	New Orleans	(unknown)	No explosion	Removed by bomb squad	3-in long bamboo with powder and fuse
8/[illegible]/74	Kennedy	Cargo building	No explosion	Removed	Cardboard container with explosive powder, fireworks fuse
[illegible]/74	Los Angeles	Locker	3 killed, 34 injured	—	—
[illegible]/74	Johnstown-Cambria, Pa.	Hangar	Hangar and aircraft destroyed	—	Probable incendiary (in 55-gal drum)
8/2[illegible]/74	O'Hare	Men's room	Commode damaged	—	Probably firecrackers
9/16/74	Boston	Airline baggage room	Substantial damage	Bomb was in an unclaimed suitcase destined for Tel Aviv	Incendiary (?)
3/15/75	San Francisco	Near ticket counter	Minor damage	—	Probably firecracker
5/22/75	Honolulu	Lost & found baggage area	Did not detonate	—	Crude pipe bomb
6/27/75	Kingsford, Mich.	Storage area	No explosion	Removed	—
7/22/75	Tampa	Baggage cart	1 injured	—	Firecrackers
[illegible]/17/75	[illegible]	Locker	Lockers and ceiling destroyed	—	—
[illegible]/75	Miami	Downtown Airlines Office	No explosion	Discovered by janitor disarmed by bomb squad	Time bomb
11/[illegible]/75	Buffalo	Baggage claim area (2 bags)	No explosion	Checked bags unclaimed after flight, timers turned off (inadvertently)	Black powder and gasoline
11/27/75	Miami	Bahamasair aircraft. Behind wall panel in lavatory	No explosion	Removed	—
12/29/75	La Guardia	Locker	11 killed, 70 injured; substantial damage	—	Dynamite and RDX[a]

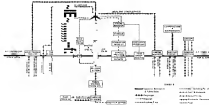
[a] FAA indicates [illegible] disagree with this assessment.

SOURCE: FAA Civil Aviation Security Service.

parcel can be placed aboard a specific aircraft for subsequent pickup are treated in the same way as freight or mail by most airlines.

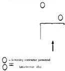
As a result of the hijacking threat in the mid-1970's, a set of procedures were developed to deal with passengers, checked baggage, and carry-on baggage. Figure 24 (from FAA report FAA-R D 78-66) shows a schematic of the passenger and carry-on luggage-screening systems. Passengers must pass through a magnetometer which will trigger an alarm upon detection of a significant metal mass, such as a gun or knife. If the alarm is triggered, the passenger is instructed to remove any metal objects such as keys, and repeat through the magnetometer. If an alarm still rings, he is searched by a hand-held magnetometer and subject to a patdown search if the alarm persists. FAA estimates that the probability of detection of guns or knives by the magnetometers, hand magnetometers and patdown are 0.95, 0.98, and 0.95 respectively adding up to an overall detection probability

Figure 23.—Schematic Airport Security System



SOURCE: FAA report FAA-RD-77-36.

Figure 24.—Passenger/Hand Baggage Screening Station


○ = Screening contractor personnel
○ = Law enforcement officer

SOURCE: FAA report No. FAA-RD-77-28

of .991.* The system is not designed to detect bombs, but FAA estimates that the probability of detecting a bomb is .917.

Carry-on baggage is screened either by an X-ray examination or by visual hand search (only at small airports or when the X-ray machines are nonoperable). FAA estimates that the probability of detecting guns and bombs in carry-on baggage is .991 and .918 respectively.

FAA estimates are probably high, especially for the X-ray detection of illegal materials in hand baggage. Magnetometers are set to a wide range of sensitivities. One may trigger on a small key ring while another may fail to trigger on a sizable metal mass. X-ray attendants are generally paid at, or near, the minimum wage, have little training, and must deal with the problem of maintaining alertness for long hours while performing an extremely dull job. While an attendant may well recognize a gun, particularly at the start of a shift, it is doubtful that a cleverly constructed explosive device would be detected.

Notwithstanding the above limitations, the use of magnetometers and X-ray machines coupled with a search profile of likely hijackers has resulted in the recovery of an impressive amount of hardware and the arrest of substantial numbers of people, as shown in table 57 (from FAA report FAA-R D-77-28), as well as the virtual halt of hijackings of U.S. domestic airlines.

The current procedure for screening checked baggage consists simply of ensuring that baggage can only be checked by a passenger with a valid ticket. When checking baggage at curbside or at the check-in counter, the

Table 57.—Results of Civil Aviation Security Program Passenger Screening

	1972	1973	1974	1975
Passengers (millions)	192	203	201	202
Passengers denied boarding	8,205	3,456	2,663	(a)
Referrals to law enforcement	(a)	(a)	(a)	2,370
Persons arrested	3,656	3,156	3,51	2,416
Airline offenses detected				
Carrying weapons or explosives aboard aircraft	779	798	1,147	1,364
Giving false information	244	858	1,485	327
Weapons detected				
Firearms	3,9	2,982	2,450	6,783
Explosive devices	10	3,458	8,983	116
Ammunition, fireworks	(a)	(a)	(a)	17,047
Knives	11,316	23,290	21,958	48,319
Other	3,213	26,740	28,254	55,500

a Figures not available.
b [illegible]

SOURCE: FAA Semiannual Report to Congress on the Effectiveness of Passenger Screening procedures, U.S. Civil Aviation Security Service.

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* The total probability of detection must be less than the probability of detection by the magnetometer, as no subsequent searches are conducted on those passengers who do not trigger the magnetometer. Total detection probability then is: PDI (Fo (PD) (PDN)

passenger must show his ticket. The system can be totally defeated by anyone willing to buy a ticket he does not use by convincing someone to check a piece of luggage for him or by a suicidal passenger.

EL AL does hand search each piece of checked baggage before it is boarded, as do the British and French for Concorde flights. Spot checks are made at most airports, particularly if the passenger is identified as matching the hijacker profile, or in times of high perceived bombing threat.

In recognition of the fact that all but one casualty in recent years in domestic airlines or at domestic airports have been due to bombs placed in lockers, most airports have either removed the lockers entirely or placed them behind the security inspection gates.

In summary, most bombings take place at targets that have no means of detecting bombs. Some high-value targets check incoming parcels and require identification. Airport procedures are quite effective in finding guns in carry-on luggage or on the person of a passenger, but much less effective in finding bombs. The probability of finding a bomb in checked baggage is low and essentially nil for courier service, mail, or freight.

Current Antibomber Procedures

The predetonation antibomber procedures followed by security personnel at airports are typical of the entire security industry. Effort is primarily directed at prevention — the best procedure is to not allow bombs to reach the secured areas of the airport or the aircraft.

The antibomber procedures of most law enforcement personnel are primarily aimed at the apprehension and conviction of criminal bombers, normally starting after a criminal bombing has occurred. The actual usage and intensity of the effort will vary with the severity of the bombing and will be somewhat different for different parts of the country.

The first step in the postdetonation investigation is to secure the area of the bombing, both to ensure that no further danger exists from unexploded material and to preserve whatever clues remain in the area.

After the area is secured, a search is made for physical evidence. This search has two objectives—evidence of the presence of the perpetrator and evidence of the bomb. Traces of the perpetrator include small pieces of clothing, hair, fingerprints, footprints, and possible tire tracks. Fingerprints, in the rare cases they are found, provide a clue to the identity of the perpetrator; the other evidence would be primarily used to tie the suspect to the crime after he has been apprehended by other means. Evidence from the bomb includes undetonated explosives and parts of the container, the detonator, and the timing system. Debris from the explosive is also collected for laboratory analysis.

If the bomb does not fully detonate, the date-shift code information may be recoverable, providing a clue to the source of explosives and a list of the last legal purchasers. If the device fully detonates, the parts of the timer and container can provide some information to start an investigation, but the leads so generated are quite indirect. The debris is more likely to furnish intelligence information such as connecting a particular bombing with similar bombings.

The next step in the investigation is a laboratory analysis of the debris and a followup investigation to attempt to trace the perpetrator from whatever clues are available. The laboratory attempts to characterize the physical evidence obtained, including an attempt to determine the type of explosive used. The laboratory evidence could provide clues in the search for the perpetrator, but more likely provides confirmatory evidence and intelligence. Armed with the data provided by the search of the bomb scene and laboratory analysis, the investigator attempts to trace and apprehend the perpetrator.

In addition to physical evidence, law enforcement agencies question witnesses, attempt to get information from informants, and exercise the resources brought to bear to solve any major crime.

The amount of time spent by law enforcement investigators at the bomb scene, in the laboratory and working in the investigation depends on the seriousness of the bombing, the workload, and to some extent the location. A bombing homicide would command considerably more resources than a vandal blowing up a mailbox.

In addition to the postdetonation investigations described above, law enforcement agencies engage in undercover infiltration of bomber groups, undercover monitoring for the services of bombers, surveillance of expected targets, and gathering of intelligence concerning expected perpetrators or groups of perpetrators. Sometimes an informant volunteers valuable information. Clues from collateral crimes such as theft of explosives or buying timers with a bad check sometimes provide additional clues. Perpetrators are even occasionally apprehended in the act of placing a bomb by routine law enforcement patrol of the area.

A further mechanism which tends to facilitate law enforcement efforts is the occurrence of accidental detonations while bombs are being fabricated or placed. Table 68, taken from FBI data, shows the number of premature detonations and the casualties caused by these detonations for the period 1974 through 1977. During that period, approximately 23 percent of all deaths by bombings and 14 percent of all injuries were to perpetrators as a result of premature detonations. A premature detonation often provides considerably more evidence than a bombing, as the explosion often takes place in the residence or vehicle of the perpetrator and with the perpetrator present. This information can lead to the arrest of other members of the perpetrator group.

Table 68.—Premature Detonation Statistics

Year	Incidents	Injuries	Deaths
1974.	29	31	[illegible]
1975.	37	53	2
1976.	42	42	[illegible]
1977	29	34	1
1978.	53	43	5

SOURCE: FBI data.

Given the penalty of a case to work with, law enforcement personnel are not able to effectively combat criminal bombers. Perpetrators of fewer than 10 percent of all bombings are brought to trial. Considerably fewer than half of those tried are convicted, resulting in a rate of only a few percent for the successful solving of criminal bombings.

DISCUSSION OF TAGGANT UTILITY

Given that identification taggants are able to survive the detonation and be recovered, that detection sensors can be developed which will detect taggant vapors in the parts-per-trillion concentration regime, and that taggants can be safely added to explosives, what would be the utility to law enforcement and security personnel of the taggant program? Possible utility attributes would include increased intelligence information; methods to decrease the theft of explosives; increased rates of apprehension and conviction of criminal bombers; deterrence of potential bombers; and an increased rate of detection of bombs at potential target sites. These issues are discussed in this section; the discussion is primarily qualitative, as little quantitative data is available.

In the initial discussion, the assumption is made that perpetrators make no response to a taggant program. The range of responses available to perpetrators, their likelihood of use, and their effects on a taggant program are discussed in the following section.

Deterrence

Supporters of a taggant program believe that both identification and detection taggants can cause some portion of the criminal bomber population to reconsider a planned incident and decide to either abandon the plan or modify it in a way beneficial to society. The deterrent effect of the identification and detection taggants is quite different, and should be considered separately. The deterrent effect that an identification taggant may have on a criminal bomber would be to lead him to perceive an increased likelihood of his possible capture, arrest, and conviction. This differs significantly from the deterrent effect of the detection taggants, in which the bomber perceives a decreased likelihood of a successful completion of the criminal bombing as well as an increased arrest probability.

A good deal of study has been conducted on the general subject of the efficacy of punishment on behavior modification, and on the deterrent value of prison sentences (or death) on criminals. The results are not coherent, however, and it is not possible to make a quantitative estimate of the percentage of bombers who would be deterred by knowledge that commercial explosives contain identification taggants. It seems reasonable to expect some deterrence, however, a point made by most of the law enforcement personnel contacted either personally or by questionnaire. Most law enforcement personnel felt the effect would be small or moderate, although approximately 30 percent predicted a substantial deterrent effect (over 25 percent of bombers would be deterred). The deterrence effect was felt to be most effective in preventing revenge bombings (almost 30 percent of the law enforcement personnel estimated a substantial effect) and crime-of-passion bombings (40 percent) and least effective in preventing bombings by terrorists, criminals, and psychopaths (approximately 25 percent of the respondents felt a substantial deterrent effect would be present for these bombers from identification taggants). These results are shown in more detail in appendix 3.

A dedicated terrorist is primarily interested in attracting attention to his cause (and less so in self-protection); a professional criminal recognizes the risk of arrest as a cost of doing business; a psychopath may either feel invincible or doesn't care about the personal aftermath of his crime. These criminal bombers may not be greatly deterred by the increased probability of arrest that identification taggants would provide; however, they may well modify their bombing plans if detection taggants significantly decrease the probability that they will succeed in their bombing mission. Whether the bombers would be deterred from committing a crime, or would modify the type of crime, is uncertain and would depend to some extent on the type of bomber, as well as the target type.

Many targets, such as residences, vehicles, and commercial establishments, would not be protected by detection taggant sensors (about 80 percent of bombings in 1977 and 1978 were of this type); the deterrence effect of detection taggants for bombers who plan to attack that class of target would therefore be small. For bombings which currently are planned against the remaining targets, the presence of detection taggants in commercial explosives and deployed sensors could modify the plan in several ways. Fear of detection taggants could lead bombers to shift to unprotected targets, or a less vulnerable, more accessible portion of the target complex (a bomb could be planted against an outside wall rather than within a Government building, for instance). Alternatively, fear of detection taggants could lead to one of the countermeasure responses described in the next section.

Some guidance on the deterrent effect that a program of detection taggants and sensors could provide to high-valued targets can be gained by analogy to the effectiveness of the current antihijacking procedures at airports. Hijacking statistics are summarized in table 99. Between 20 and 30 commercial airliners originating from domestic airports were hijacked each year between 1969 and 1972. In 1973, a series of antihijacking measures became fully implemented in the United States, which included 100 percent passenger screening by magnetometers, X-ray examination of carry-on luggage, and development of a hijacker personality profile. The number of hijackings dropped dramatically — to a single incident in 1973 and an average of 4.5 per year since.

Some foreign countries have instituted antihijacking procedures as well, although not as

Table 66.—Commercial Airline Hijacking Statistics by Year

Year	Hijackings U.S. origin[b]	Hijackings foreign origin
1961-67	4	45
1968	18	14
1969	38	40
1970	30	51
1971	24	25
1972	27	29
1973[a]		7
1974	3	7
1975	6	1
1976	4	13
1977	5	NA
1978	5	NA

a U.S. antihijacking measures became fully effective.
b U.S. airlines irrespective of point of origin.
NA = not available.

SOURCE: [illegible]

nationally as has the United States. As a result, the foreign hijackings declined approximately 60 percent when the 1969-72 period is compared with the 1973-77 period, while hijackings from domestic airports declined almost 90 percent in that same period.

While part of this drop may have been due to additional measures such as the use of armed sky marshals for a period on the most vulnerable routes and the gradual erosion of a friendly welcome for hijackers at some foreign countries, a good deal of it is probably due to the deterrent effect of a visible screening system. In fact, large numbers of weapons have been reported recovered from trash containers, potted plants, and other hiding places as a result of the weapon carrier being confronted with an operating screening system. That the deterrent is not 100-percent effective is clearly shown by the number of weapons currently confiscated by the screening process as shown in table 67.

In summary, it is not possible to quantify the number or percentage of bombers who would be deterred by a taggant program. Identification and detection taggants will probably deter some bombers, particularly revenge bombers and those committing crimes of passion. Detection taggants will deter bombers from attacking protected targets, perhaps at the expense of more frequent attacks on unprotected targets. Law enforcement personnel indicated that, overall, about the same magnitude of deterrence would be expected for each type of taggant, perhaps reflecting the larger value of detection taggants for those targets protected by detection sensors and the total lack of deterrent for those not visibly protected.

Bomb Detection—Target Protection

Detection taggants should greatly increase the probability of detecting explosives containing the taggants and thus increase the protection of the targets at which detection sensors would be deployed, either permanently or in response to a heightened perceived threat. Again, no data exists that would allow quantitative estimates of the detection effectiveness. As indicated in the previous section, FAA esti-

Photo credit: U.S. Department of Transportation

Typical airline passenger screening point mates that the current passenger and carry-on baggage screening systems at airports have an average probability of detecting guns or knives of over 80 percent, while they estimate less than a 20 percent detection probability for explosives. If the assumption is made that a detection sensor would have the same effectiveness in detecting bombs that the current systems have for detecting guns, a fourfold increase in effectiveness would be expected. If the Aerospace Corp. prototype specification of 0.999 probability of detection is met by the fielded system, then essentially full protection would be available to those targets protected by a detection taggant sensor. The term full protection must be qualified. It refers to bombs that are fabricated from tagged commercial explosives and do not have a sufficient seal to prevent escape of the taggant molecule. No protection is offered for bombs fabricated from untagged explosives (homemade, taggant removed, foreign supply, explosives fabricated prior to the taggant program) or from explosives with a sufficient seal.

It is unlikely that a detection taggant program would result in a significant increase in the number of bombs detected, as few of the current bombings are directed at the type of high value, limited access targets at which detection sensors would be located. The utility of the detection taggant system would be in eliminating or greatly decreasing the low number of bombings which occur at these targets, each of which can cause catastrophic damage and casualties.

The above discussion addressed the utility of fixed detection taggant sensors. Portable sensors have an additional function — locating a bomb whose approximate location is known or suspected. Law enforcement and security personnel are often notified of a bomb threat through tips, calls claiming credit for planting a bomb, and extortion. Current procedure is to evacuate the premises and then conduct a time-consuming search, using personnel and perhaps trained dogs, in an attempt to locate the bomb. The disruption caused by a bomb threat can be quite costly; a recent evacuation of the World Trade Center in New York is estimated to have cost several million dollars in lost time. The use of a portable sensor could significantly cut down on the time for a search and increase the probability of finding a bomb. It is possible that the existence and deployment of portable detection sensors would deter some bombers from planting bombs, particularly as an extortion device, as well as act to deter bomb hoaxes. BATF reported 105 hoax device incidents in 1977 and 87 in 1978, so reducing the number or reducing the time lost from each could have a significant economic impact.

The additional utility of portable detection sensors was noted by law enforcement personnel returning the questionnaire. Approximately 65 percent felt that a portable sensor, needing no skilled operator, would have a high utility (deter over 25 percent of bombers), while less than 50 percent felt that a stationary sensor would have high utility. Similarly the respondents felt that portable units were superior to nonportable units for each type of target suggested. The differences were small for targets such as airports, large Government buildings, and nuclear power stations, but ranged up to more than 5 to 1 for targets such as schools and bus and train depots.

An important limitation to the detection of explosives by any means should be noted. It is possible to defeat any type of detector. Therefore, failure to detect a bomb cannot be taken as proof that no bomb exists. The easier it is to defeat the sensor, the greater the limitations to the utility of the system. A system that detected 57 percent of the bombs would therefore be useful only as a screen. A system that detected 99.9 percent of the bombs would not only screen out twice as many bombs, but could be used to give a high probability that no bombs were present, significantly decreasing search time for bombs, more easily detecting hoaxes, and giving more useful decision data for dealing with threats or extortion attempts.

Bomber Apprehension

The current procedure for the apprehension of criminal bombers consists of three phases:

1. the postdetonation search of the area for physical evidence and subsequent laboratory analysis;
2. the investigation based on the results of the analysis of the physical evidence; and
3. intelligence gathering, used as an input to the investigation or to direct surveillance of suspected perpetrators or suspected targets.

A great deal of effort is currently spent on the postdetonation search and analysis of physical evidence from a criminal bombing. The purpose of this search is to attempt to generate leads to help in the apprehension and conviction of criminal bombers, either directly from clues found in the debris or as a result of intelligence information gathered from an examination of bombings.

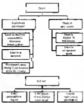
The search for evidence phase includes a detailed analysis to try and determine the type of explosive used and to find and examine any parts of the bomb, such as components of the timing device which may have survived the detonation. This evidence, together with any evidence of the presence of the perpetrator (such as hair or footprints) serves as the starting point for the investigative phase. Laboratory analysis is currently successful in determining the type of explosive used approximately 80 percent of the time, but experts estimate that the manufacturer can be identified in less than 10 percent of current cases undergoing intensive analysis. Parts of the detonator and timing device usually survive the detonation, and in many cases currently provide the best initial leads from which to launch an investigation.

The investigative phase consists primarily of trying to generate some type of lead to the perpetrator from the physical evidence gathered, as well as tracking leads provided by informants or witnesses and attempts to correlate the characteristics of the bombing with similar instances. A great deal of effort may be expended, for instance, in investigating the sources of a common clock used as the timing mechanism.

The addition of identification taggants to explosives would aid the investigatory efforts of law enforcement personnel in a number of ways, provided that the taggants survive the detonation and are recoverable from the explosive debris. In order for the taggant information to be useful, however, the bombing must be of sufficient importance (in terms of property damage, notoriety generated, or casualties produced) to warrant a thorough investigation. In such cases, identification taggants will provide much more definitive information of much less effort by the investigating team. Equally important, the information can be made available quickly—in a matter of hours if necessary, rather than the days or weeks it may take to generate whatever data can be generated by conventional means. The taggants provide a good starting point for an investigation as they directly indicate the type of explosive used, manufacturer, and time of manufacture, and provide a list of the last legal purchasers. This information may lead directly to a bomber who purchased the explosives legally, provide a limited number of suspects for intensive investigation, tie reported thefts of explosives to bombings, provide leads to an unreported theft of explosives, or provide indirect information to limit the scope of an investigation, such as to a specific geographical region of the country. Some of the ways in which identification taggants can contribute to an investigation are shown schematically in figure 25.

There will be some cases in which the perpetrator legally buys the explosive and subsequently uses it to commit a criminal bombing. In some of these cases the bomber would not otherwise be identified with the bombing. In

Figure 29.—Schematic Illustration of Identification Taggant Utility in Criminal Investigation



Direct
Explosives purchased
Theft of explosives
Lead to multiple suspects for intensive investigation
Lead to a suspect
Purchased using phony ID or through a third party
Identify source of explosives
Lead to unreported theft
Indirect
Limit geographic region
Limit types of explosives considered
Provide intelligence information

SOURCE: Office of Technology Assessment.

others, the taggants add a strong link in a chain of evidence, which may help to obtain a conviction. A chain-of-evidence example recently occurred at Sparrows Point, Md., where a bomb planted in a pickup truck killed the driver. A search was made of the bomb scene and the physical evidence subsequently examined in the BATF national laboratory. The laboratory analysis indicated that the explosive used in the incident had been tagged as part of the pilot plant taggant program. The list of legal purchasers of that lot of explosives included James McFillin, one of the prime suspects in the bombing. McFillin was found guilty on December 19, 1979.

Even in those cases where the list of last legal purchasers does not contain an obvious suspect, it provides a means of identifying a limited number of people for a subsequent thorough investigation.

In some cases, explosives will be legally purchased, but with phony identification or by a third party not directly involved in the commission of the bombing. When phony identification is used, an intensive investigation could still provide a viable lead to the purchaser. Although the purchaser's real name and address would not be directly provided by the list of purchasers, a location, a time of purchase, and a witness to the purchase would have been provided. Similarly, for the cases involving a third-party purchase, that intermediary might be identifiable, providing a good lead to the perpetrator. It may also be helpful to know the time frame when explosives used in a crime were obtained.

Some of the explosives used in criminal bombings are currently stolen, and it may be that a taggant program would increase the incidence of explosive theft, as discussed in the next section. Identification taggants would provide information of considerable utility to an investigation of a criminal bombing, even for explosives that turn out to have been stolen. The list of last legal purchasers should provide information as to the source from which the explosives were stolen. In some cases the theft of explosives will have been reported. Identification of the source of the explosives provides intelligence information on the sources and disposition of explosives for criminal bombings. It may also provide a lead directly to the perpetrators of a bombing by establishing a connection between specific thefts and specific bombings. It may be difficult to establish a motive or any other useful lead for an isolated theft, but tying it to specific bombings may provide that lead, particularly if the explosives are stolen with the help of an employee.

In some cases the explosive theft may not be reported, perhaps due to the surreptitious theft by an employee of small amounts of explosives over a period of time. Identifying a source by the use of taggants could result in leads to the employee thief, and through him perhaps to the criminal bomber.

While not directly related to an investigation of a criminal bombing, identification of a particular facility as the source of stolen explosives would help pinpoint those facilities, or types of facilities, that are in need of increased security for their explosives.

The value of the list of last legal purchasers will depend somewhat on the length of the list. A trace which indicates that the full taggant batch of explosives was sold directly to a mine by the explosives manufacturer obviously provides a more immediately useful lead than a trace which shows thousands of purchasers of a lot of smokeless powder. Even the list with thousands of legal purchasers would provide a better starting place for an investigation than the types of information generally available with present methods. For example, investigators attempt to trace timing mechanisms even though thousands of people may have purchased the model of clock that was used and there are no records available that would turn up their names.

It is rather unlikely that the trace would turn up a list of thousands of names as likely perpetrators of a significant or catastrophic bombing, even if black or smokeless powder was used as the filler. The types of bombings likely to warrant a detailed investigation are unlikely to be caused by 1 lb of gunpowder, which would eliminate most of the people on the list either by narrowing the list to those purchasing more than 1 lb of the same lot, or by providing multiple traces of the multiple lots used in the filler. When effects such as the geographical distribution of the tagged gunpowder lot are also taken into consideration, the list of viable names is likely to be much smaller than would appear to be the case on the surface.

BATF traced the number of entities that were involved in the manufacture, distribution, and ultimate end use of the unique taggant lots produced during the pilot test program; the number ranged between 2 and 68. The size of the uniquely tagged batch varied from 12,000 to 28,000 lb, with the number of entities directly but weakly related to the taggant batch size. The batch involving the most entities (68) included the manufacturer, 3 primary distributors, and 21 secondary and 43 tertiary distribution points.

The above discussion is relevant when the taggant trace produces information directly identifying a suspect, a group of suspects, or a source of explosives theft. In some instances it may not be possible to directly narrow the list of possible suspects. Examples would include unrecovered thefts with no inside help, purchases from which no obvious leads turned up, or traces in which the list of last legal purchasers was too large to provide a reasonable starting point for investigation of all of the individuals involved. In these cases, the identification taggant traces, including the manufacturer, time of manufacture, specific product, and list of distributors and ultimate purchasers would still provide indirect information of use to the investigation. Examples of indirect information might be data that limit the investigation to a small geographic region of the country, identification of the type and manufacturer of the explosives, and an indication of when the explosives were acquired by the bomber. Even the indirect information provides more data to the law enforcement investigators than currently available after extensive laboratory and field investigation of postdetonation debris.

In addition to providing both direct and indirect leads to the investigation of criminal bombings, taggants can contribute considerable intelligence information.

Intelligence Concerning Criminal Bomber Activities

The gathering and integrating of intelligence concerning the activity of criminal bombers and groups of bombers is a time-consuming process which is a necessary adjunct of control by law enforcement agencies. Identification taggants would greatly facilitate law enforcement intelligence activities, particularly in monitoring the range of activities of bomber groups, the theft and disposition of explosives, cooperation between various bomber groups and between domestic bomber groups and foreign organizations, and keeping track of current sources of explosives for criminal bombers. Intelligence information is particularly useful in combating the repeat bomber, and may provide the only effective method to generate leads to the most sophisticated bombers — professional criminals and terrorists.

Strategic data banks receiving information from a variety of domestic and foreign sources have successfully identified patterns and trends that have led to a better understanding and arrests and convictions of members of international narcotics rings, high finance swindlers, and terrorists. Taggants could enhance the ability of such data banks to facilitate identification of terrorist objectives, leading toward arrests and convictions of terrorist bombers. Taggants, by identifying known sources of terrorist bombs and bombs used by other criminal organizations as well, would help intelligence analysts differentiate among several groups which may claim, or which may seem to be responsible for, a particular bombing incident, separating out the group directly responsible. The British taggant system, which apparently consists of identifier threads dispersed in the explosives, is used primarily as an apparatus for gathering intelligence about criminal bombers. A few specific examples of how intelligence information could be used for bomber control are instructive.

Some criminal bombers operate in a single location with no activities beyond that area. Others range over a fairly wide geographic area. If taggants recovered from a bombing indicate that the explosives were purchased in the area of the bombing, then a local group or individual is probably responsible. On the other hand, if the explosives were stolen or purchased in one part of the country and used in another, that would indicate that either a group with a considerable geographic span of activity was involved, or that there was cooperation between various groups of criminal bombers.

BATF currently keeps a record of the amount of explosives stolen, recovered, and expended in bombings. While it is possible to trace and allocate cap-sensitive high explosives that are recovered in their original cartridges (by the date-shift code stamped on the cartridge), it is extremely difficult to identify the source of explosives that have been detonated. Recovery of taggants would allow a much more accurate record to be kept of the use to which stolen explosives are put.

At present there appears to be little cooperation among domestic groups responsible for criminal bombings (terrorists and professional criminals in particular) or between these groups and foreign organizations. That is not the case, however, for foreign groups that engage in bombings or other terrorist activities abroad. Some terrorist activities abroad have involved groups from two or even three different countries separated widely in geography. Intelligence analysts predict that coordinated activity of that sort may soon be seen in the United States. Taggants could help to identify cases of intergroup activity. As an example, explosives may be stolen, and the modus operandi of the theft or a claim of credit for theft indicates that one group was responsible. If the taggants recovered from the debris of a criminal bombing (identified as having been caused by a different perpetrator) indicate the use of those explosives, then a link may be postulated to exist.

A final example illustrates the predictive value of bombing intelligence that would be available from a taggant program. Analysis of the explosives used in a series of bombings could indicate they were all from the same taggant lot. Analysis of the pattern of the bombing could be useful in predicting a geographic area for a subsequent bombing or in predicting a time for a bombing by the group involved, allowing increased surveillance of individuals in the group (if identified) or of potential targets.

Prosecution of Criminal Bombers

There is rarely a single piece of evidence that so clearly ties a perpetrator to a criminal bombing that additional evidence would not enhance the case for the prosecution. A limited amount of data on the use of the date-shift code indicates that taggants may forge an important link in the chain of evidence against a criminal bomber, resulting in a higher rate of convictions than would be possible without that link. For undetonated bombs the date-shift code provides the same information as identification taggants would provide for the postdetonation case. No total review of the cases involving explosives recovered from malfunctioning bombs has been conducted. However, a limited set of 55 cases was examined by BATF. In that sample six cases were forwarded for prosecution (11 percent). That is twice the percent forwarded in cases that did not include date-shift code data. Similar results were obtained by MSA during a review of BATF data. Of the 18 bombing attempts they reviewed, the date-shift code proved useful in 40 percent of the cases, was not useful in 50 percent of the cases, and was of questionable utility in 10 percent. While the results were positive in both cases, the extremely small sample size makes it impossible to draw significant conclusions. The Institute of Makers of Explosives (IME) has informed OTA that testimony from manufacturers to establish the source of explosives with a given date-shift code is commonly requested in criminal prosecutions, but that such requests are very infrequent. IME estimates that less than 1 percent of all traces lead to a prosecution.

As one specific example, the prosecution in the McFillin case believes that taggants were a key piece of evidence in that case and that the taggant evidence was valuable in court.

Taggant Utility by Type of Perpetrator

Taggants may well be more effective in contributing to the arrest and conviction of certain types of criminal bombers than of others due to the varying ability of different types of perpetrators to develop effective countermeasures in response to taggant programs, as well as to the nature of the bombings and targets. These countermeasures and their effects in limiting taggant utility are discussed in detail in the next section.

Vandals are not likely to be greatly affected as these bombings generally cause little damage and would not normally initiate the field laboratory and investigative procedures necessary to utilize the information available from identification taggants. On the other hand, bombings by professional criminals often involve homicide and bombings by terrorists generate considerable public attention, both of which are likely to initiate extensive investigations. To the extent that the more sophisticated of these groups make use of countermeasures, an operational taggant program may not add much to the likelihood of their arrest and conviction. Psychopaths are likely to engage in bombings that initiate a thorough investigation, may well attack targets protected by detection sensors, and are unlikely to have the resources to generate effective countermeasures. Taggants should be particularly effective in these cases.

The law enforcement respondents to the questionnaire indicated a differing utility for taggants against the various bomber categories. As an example, almost 57 percent estimated that identification taggants would result in a significantly higher arrest rate for revenge bombings, and over 40 percent estimated significantly higher arrests for crime-of-passion bombings by psychopaths, while less than 27 percent estimated a significantly higher arrest rate for bombings by terrorists and organized crime. A significantly higher rate meant an increase in the arrest rate by more than 25 percent. Similar estimates were made for the use of detection taggants.

Utility of Taggants to Update the Taggant Program

BATF plans to implement the taggant program only for those explosive materials that have been identified as being used extensively by criminal bombers. If continuing analysis of bombing debris shows that tagged explosives are not used in a large number of cases, then the BATF plan would need modification. Similarly, if some explosives that are tagged are not identified as being used in bombings, then those explosive materials should be considered as candidates for exclusion from the program.

Nonbomber Control Utility of Taggants

The Bureau of Mines is very interested in the use of identification taggants to determine the types of explosives used when an accident occurs in a mine. Some mine operators are suspected of using nonpermissible explosives in underground coal mines. Permissible explosives have been specifically tested for low flame emission and certified for use in underground coal mines—other explosives may not be used. If nonpermissibles are identified as being used illegally, the appropriate action can be taken.

Similarly, taggants could be used to identify the cause of an explosion. If an explosion were to occur at a natural gas plant, for instance, then it might be difficult to determine if the explosion were an accident or caused by a bomb. The resolution of cause is important both to law enforcement personnel and to the insurance industry. A similar resolution of cause could be of interest in investigating possible insurance fraud cases.

POSSIBLE BOMBER COUNTERMEASURES IN RESPONSE TO A TAGGANT PROGRAM

The above discussion assumes that criminal bombers do not respond to the introduction of a taggant program. There are a number of countermeasures the bomber can take, however, which may decrease the utility of a taggant program. Only a limited number of bombers would respond to the taggant program, and those criminal bombers who seek to evade the effects of a taggant program are likely to encounter additional risks or require substantial training and technical knowledge.

Among the possible responses of a criminal bomber to an identification taggant program are:

- removal of the taggant,
- fabrication of homemade explosives,
- switch to incendiary devices,
- use of blasting agents, if they are not tagged,
- theft of explosives,
- black-market purchase of explosives,
- use of explosives manufactured before the taggant program is implemented, and
- resorting to another type of unlawful activity such as assassination or kidnapping.

In addition to the above responses, the use of detection taggants can be defeated by providing a seal between the explosives and the detection taggant sensors. It is also possible that the detection taggant sensors could be purposely "triggered" or "spooked" by placing detection taggant materials or chemicals which the detection taggant sensor could not distinguish from detection taggants in or on nonexplosive material.

The appropriateness and effectiveness of the various responses in terms of possible limitation to the utility of a taggant program are a function of the resources, motivation, and aim of the various types of criminal bombers. Table 78 briefly summarizes the likely response countermeasures of each type of bomber, and how effective these responses are likely to be. Effectiveness in this sense includes both the likelihood of successfully accomplishing the response and the appropriateness of the action in fulfilling the primary aim of the criminal bomber. It is interesting to note that approximately half of the law enforcement respondents to the questionnaire estimated that the less sophisticated bombers would initiate no response to an identification taggant program, while almost 40 percent felt that even the most sophisticated bombers would not initiate response countermeasures. Each of the response countermeasures is briefly discussed below.

The baseline 3M identification taggants contain both a magnetic layer and a fluorescent layer to aid in recovery after a detonation. The taggants could therefore be removed from

Table 21.—Possible Perpetrator Response Countermeasures to a Taggant Program

	Criminal		Terrorist			Mentally disturbed			Other	
Countermeasures	Unsophisticated	Sophisticated	Political	Separatist	Revolutionary	Disenchanted	Vengeful	Pathological	Vandals	Experimenters
Taggant removal	—	M	H	H	L-M	—	—			L-M
Fabrication of explosives	L	H	H	M	M	L	L	L	L	L-M
Nonmilitary devices	L	—	L	L	M	M	M	M	M-H	L-M
Use of blasting agents if untagged	L	H	H	M	M	L	L	L	L	M
Theft, commercial	M	L	M-H	M-H	L-M	L-M	L-M	L-M		M
Theft, military	L		L	L	L	—	—	L		—
Illegal sources	L	H	H	H	—	—	—	—		—
Use of explosives manufactured before implementation of tagging	L	L	M	L	—	—	—	—		—
Vapor seals	—	L-M	L-M		L	—	—	L		—
Other tactics		L-M	H	H	H	—	L-M	M		—

[a] Unlikely to be attempted.
[b] Letters indicate possibility of success in the attempted countermeasure: L=low, M=medium, H=high.

SOURCE: Office of Technology Assessment.

powdery explosives. By using a magnet the process would be both easy and safe and would require less than an hour for a typical bomb. In order to hinder the countermeasure, taggants have been manufactured without a magnetic layer. If a powdery explosive were tagged with a mixture of magnetic and nonmagnetic taggants, then the use of a magnet would enable a criminal to remove only a portion of the taggants; the remainder would be present after an explosion, although they would be somewhat more difficult to recover than the baseline taggant. If the criminal were deterred from attempting magnetic removal by the knowledge that about half the taggants were nonmagnetic, then postdetonation recovery would be only marginally more difficult than the baseline case.

Another possible technique for removing taggants from an explosive is to use a black light to identify the taggants by their fluorescence and then remove them with a tweezer. This process is safer but more difficult than magnetic separation and would probably require many hours of painstaking effort for a typical bomb. Unlike magnetic separation, it could be used to remove taggants from explosives that are tacky rather than powdery. It has been proposed that the encapsulation of the taggants be made opaque and matched to the color of the explosive in order to render such removal impossible. Since the encapsulant would be melted by the heat of a detonation, postdetonation recovery would not be affected. Although it should not be difficult to develop an opaque encapsulant, this has not yet been done. Opaque encapsulation would make quality control both of manufacturing taggants and of mixing them with explosives more difficult, and its cost impact has not been evaluated.

The explosives could be acetone dissolved, the taggants and other solid materials removed by filtering, and the explosive reconstituted, but that complex operation would be within the capabilities of only the professional terrorists and criminals and would be roughly equivalent in danger and difficulty to fabrication of explosives from raw materials. It was the unanimous opinion of law enforcement personnel that criminal bombers would not attempt this complex removal/reconstitution process. Reconstituted explosives would also be less reliable (less likely to detonate) than the original explosives. If detonators were tagged, some taggants would still be present after the detonation of bombs using reconstituted or homemade explosives, unless the even more difficult task of fabricating detonators was attempted.

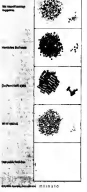
Removing taggants from some gunpowders is considerably simpler than removal from explosives. Many gunpowder grains are consider ably larger than the identification taggants, as shown in figure 26. Separation may therefore be accomplished simply by screening (if through the manufacturing process may provide that approach in some cases. Alternatively, it may be possible to agglomerate the taggants into clumps whose size roughly matches the specific grain size. However, the cost impact of such a solution was not addressed during this study.

The detection taggant vapors are microencapsulated into extremely small spheres, which form powder with fineness approaching that of talcum powder. Removal of these taggants from tacky or powdery explosives is clearly impractical and most likely impossible. There is some evidence that the taggant grains tend to adhere to gunpowder grains. The tenacity of adhesion (response to attempts to dislodge the taggants) has not been tested. It is probable, however, that the extremely small taggant powder cannot be simply separated by physical means; similar materials such as graphite do not respond. Attempts to "wash" the grains off with a solvent are likely to affect the properties of the smokeless powder.

The only viable removal technique, therefore, appears to be removal of individual identification taggants from gunpowders. As was shown in table 70, the more sophisticated criminals and terrorists could accomplish the removal with moderate to high success, while the less sophisticated terrorists and experimenters would have a somewhat lower success rate. One result of the greater practicability of removing taggants from gun powders may be to produce a shift in explosive materials used in criminal bombs by sophisticated bombers from high explosives to gunpowders. As gunpowders are significantly less energetic than cap-sensitive high explosives, such a shift could result in a significant loss of efficiency for the bombers.

In summary, taggant removal would tend to somewhat decrease the effectiveness of a taggant program in the control of the most sophisticated bombers attacking targets not protected by a detection sensor, but at some loss in efficiency by the criminal bomber. It is

Figure 26.—Size Comparison of the 3M Identification Taggant and Some Smokeless Powders



possible to make short-fusing taggant clumps which simulate the grain size of the larger powder grains, thus making taggant removal an ineffective countermeasure, but the cost of doing so has not been calculated. Alternatively, taggants could be incorporated in the grain of some, but not all powders.

Fabrication of Homemade Explosives

As noted in table 70, only the most sophisticated bombers would have a significant success in fabricating explosives. Even to these criminal bombers, the fabrication of homemade explosives would involve a somewhat higher danger of premature detonation than with commercial explosives. It is true that a number of "cookbooks" are available that describe methods of making explosives from uncontrolled materials, but many of these texts list the ingredients without describing a safe and effective fabrication process or contain errors that could result in a high accident rate or unpredictable detonations. The present incidence of premature detonations with commercial explosives while fabricating and placing bombs is high, accounting for almost 25 percent of all deaths and 15 percent of injuries from bombings. If homemade explosives are used, the number of deaths and injuries to perpetrators of bombings may climb substantially—acting as an effective bomber control mechanism.

Fabrication of detonators is a much more complex and dangerous activity than fabrication of explosive materials and could probably be accomplished only in a well-equipped central facility. The widespread use of homemade detonators would therefore require the development of a central illegal manufacturing and distribution network, implying a degree of cooperation among perpetrator groups that does not currently exist.

It was the opinion of law enforcement officials contacted that the establishment of a taggant program would tend to drive the more sophisticated criminal bombers toward the use of homemade explosives. The example provided by criminal bombers in Europe, particularly Britain and West Germany, is illustrative. Approximately 85 percent of criminal bombings in West Germany and a majority of the bombings in Britain and Ireland use homemade fillers. As the bombing statistics include both explosive and incendiary devices, the percentage of explosive bombs using homemade explosives may be somewhat less, but may still constitute a majority in all three countries. It is interesting to note that most bombs, including those with homemade explosives, use commercial detonators.

In summary, the more sophisticated criminal bombers would tend to use homemade explosives more frequently in response to the introduction of a tagging program. Such use would tend to have some detrimental effect on the utility of a taggant program although the effect would be limited by the increased risk of premature detonation and the reduced reliability and effectiveness of bombs fabricated from homemade explosives. Commercial detonators would still be needed, further limiting the effectiveness of this response, as would the elimination of some types of targets. The main threat is that over a period of time, the criminal bomber might become increasingly sophisticated in the fabrication of explosives and even of detonators and that a degree of cooperation and coordination could develop between the various terrorist and professional criminal groups. The British indicated that they face just that problem—the coordinated IRA improves its tactics and ability to fabricate explosives almost in step with the development of law enforcement control mechanisms.

Use of Incendiary Bombs

A substantial number of current bombing incidents use incendiary materials for bomb filler. Tagging of incendiary materials is not practicable, so legislation of a taggant program may cause a shift toward the greater use of incendiaries in place of explosives. However, incendiary bombs cannot be relied on to cause catastrophic damage or casualties and are therefore an appropriate filler only for some types of perpetrators and against some types of targets. It may also be harder to fabricate a reliable delay fuze for incendiary bombs.

Use of Blasting Agents

BATF has indicated that it does not plan to directly tag blasting agents such as ANFO. There are several reasons for their position. In the first place, very few criminal bombings are currently committed using blasting agents as the explosive filler. In addition, tagging the blasting caps, boosters, and detonating cord generally used to initiate the blasting agents would still ensure that taggants were present at blasting-agent bombings unless homemade detonators and boosters were used. Finally, as blasting agents represent over 50 percent of the commercial explosives currently used in the United States, directly tagging the blasting agents would have a very large cost impact. Some shift to the use of blasting agents might therefore occur if a taggant program were implemented. However, there are a few drawbacks to the use of blasting agents. As detailed in appendix E, the blasting agents are not normally cap sensitive and would therefore require a booster of some sort. Commercial boosters, very large detonators, at least one type of rocket motor used by hobbyists, or several large cherry bombs used together would be sufficient boosters. The fabrication of a bomb using a blasting agent would therefore require the acquisition and assembly of more components than would a bomb using cap-sensitive explosives or gunpowders. The assembly process would not prove a large obstacle to the more sophisticated bombers, but might well prove one to the other types of bombers. Similarly, the increased risk associated with blasting-agent bombs would depend on the knowledge and patience of the bomber.

Blasting-agent bombs would be useful against targets where the blast was the primary damage mechanism, but somewhat less useful than cap-sensitive explosives against targets in which fragment damage was the primary threat. More blast and better fragmentation would be expected from blasting-agent pipe bombs than from gunpowder pipe bombs, but the assembly process would be more complex.

Blasting agents have a density of approximately one-half that of cap-sensitive explosives; approximately twice the volume would therefore be needed, a possible limitation in some circumstances.

Theft of Explosives

Explosives can be stolen either from the military or from sources of commercial explosives. Some of the explosives used in criminal bombings are currently stolen and more may well be stolen if a taggant program is initiated. Theft of explosives would mean that the perpetrator would be required to commit a collateral crime, increasing the chance for error, the number of leads generated, and the ultimate chance of capture. As detailed previously, the use of taggants should contribute significantly to the rate of solution of explosive thefts, increasing the chance of capture above the current rate.

In addition, protection of explosives from theft could be improved and may well have to be to prevent a wholesale shift to theft as a source of explosive material if a taggant program is instituted. Security procedures for explosives storage, transportation, and use are primarily geared to prevent casual or surreptitious theft. Storage magazines have double locks and other features which would require some limited amounts of time and skill to defeat. Inventory controls currently would uncover thefts of large amounts of explosives (case lots). Transportation regulations are primarily to protect the people living along the travel route from accidental detonation. All of these could be altered to decrease the probability of explosive theft. Magazines could be made quite difficult to enter; all explosive material could be required to be stored overnight in a secure magazine (some construction sites use quite flimsy magazines; some manufacturers store sizable amounts of detonators in the assembly building overnight); and transportation of explosives could require armed guards. Tighter inventory controls including accountability for each stick of explosive at the blaster level could also be required. All of these controls, however, have cost impact. It would require investigation to determine whether their cost would be justified by their marginal utility in the face of the current and predicted bomber threat. Possible costs for increased security of explosives were not included in the OTA study. As noted above, a benefit of identification taggants is that they would help to pinpoint the places from which explosives used in crimes are stolen and thus serve as a guide to where security most needs to be tightened.

As noted earlier, military explosives are more securely guarded than commercial explosives, so criminal bombers may be expected to more frequently attempt to steal commercial explosives. As noted in table 70, the more sophisticated bombers are likely to have moderate to high success in stealing commercial explosives (although at increased risk) while the less sophisticated bombers are expected low to moderate success. No group would be expected to have significant success in stealing military explosives, an indication of the success likely for theft of commercial explosives if increased explosive security measures are implemented.

Illegal Sources

Explosives could be purchased on the black market or illegally imported from abroad. Both courses of action subject the bomber to increased risk of capture from informants or undercover agents in the former case and as a result of smuggling in the latter. Only terrorists or professional criminals with substantial resources and the ability to plan in advance are likely to be able to import explosives from abroad, or likely to make the proper black market connections.

The term black market in this context, does not refer to a sophisticated nationwide network but to a local array of entrepreneurs who deal in an illicit product for profit. This criminal element exists in nearly every major American city, and when asked could provide stolen commercial explosives or explosive materials as quickly as they could provide stolen drugs, jewelry, or television sets. A taggant program, it is believed by analysts and law enforcement experts, would increase the demand for stolen explosives, thus increasing the local market. However, experts at the two major metropolitan police agencies and two Federal law enforcement organizations with whom detailed discussions on this subject were held agree that initial increases in the black market demand would be low, as the sophisticated bombers are more likely to turn to one of the other countermeasures as a source of explosives. Moreover, taggants would help in tracing any black marketeer who dealt in stolen, but tagged, explosives.

Use of Explosives Manufactured Before a Taggant Requirement

One further countermeasure is possible—at least initially—the use of explosives manufactured prior to implementation of a taggant program. This response requires planning well ahead and storage of the explosives for a period of time. Storage would increase the risk of accidental detonation (particularly if the explosives had to be moved several times) and of the explosives being found. In addition, most commercial explosives have a limited useful lifetime. Gels, slurries, and emulsions have a limited useful life on the order of 6 months, while dynamites have a lifetime of a few years (more for the lower power dynamites). Gunpowders, boosters, detonators, and detonating cord have a useful life of tens of years.

Detection Taggant Seal

Detection taggants emit a vapor that will diffuse from the body of the explosive to permeate the container in which they are placed and be detected in the free air stream. It is possible to create a seal around the explosives, thus defeating the detection taggant system. But the construction of such a seal is difficult, cannot be accomplished without specific technical knowledge and equipment, and cannot be ac-

accomplished without the time and resources to construct such a seal. Ordinary sealing mechanisms such as placing the explosive in a paint can, using baggies, home sealing units or using activated charcoal apparently will not work, even if several are used in conjunction, as the taggants were specifically chosen for their ability to penetrate the microencapsulated membrane and the sensors are able to detect taggants at a parts per trillion concentration level. It should be noted, however, that tests under field conditions to confirm these laboratory results have not yet been conducted.

Only the more sophisticated of the criminal bombers are even likely to attempt to achieve vapor sealing, and they stand only a low to moderate chance of succeeding. One of the problems faced in trying to construct a seal is the lack of feedback — without a taggant vapor detector or other sophisticated laboratory instrument, the bomber will not be able to tell if his seal is sufficient.

"Spooking" of Detection Taggant Sensors

Detection taggant sensors could be purposely triggered or "spooked" by placing detection taggants, or other molecules similar chemically to the detection taggant that the sensors could not make the distinction, in nonexplosive materials. If several suitcases or packages within a short period of time triggered the detection taggant sensors for no apparent reason, those operating the sensor might well conclude that it was malfunctioning and disconnect it. Large amounts of taggant material might also be used to "saturate" and at least temporarily blind the sensor. It would then be possible to introduce tagged explosives into the protected area. This countermeasure would require that the bomber obtain a supply of the detection taggant material; access to detection taggants can and should be made difficult.

Shift to Other Unlawful Activity

Finally, bombers can turn to other crimes such as murder, assassination, or kidnapping. These crimes, however, are often not as open-ended as bombings and all involve a higher risk to the perpetrators than do bombings. In addition, a direct action against a visible target requires more motivation and a different temperament than does an indirect crime such as a bombing. The switch to other tactics is an appropriate response only for a subset of criminal bombers; only some of the types of bombers who would attempt to switch tactics in response to a taggant program would be successful. The small-scale criminal, the experimenter, and the [illegible] would be unlikely to turn to the other crimes. Some of the mentally disturbed would, with low to moderate success. The professional criminal can be considered a craftsman of his trade; he may not be able, either physically or emotionally, to adjust to other methods of attaining his ends. Terrorists are the most likely to switch tactics based on foreign experience and would probably be moderately to highly successful, although at greatly increased risk.

Summary

There are a variety of response countermeasures which the criminal bomber can attempt in an attempt to decrease the utility of the identification and detection taggants programs. The amount of success expected for each response varies with the skill, resources, and aim of the different types of criminal bombers. Most of the countermeasure responses carry with them an increased risk of capture, increased probability of an unreliable or premature detonation, or decreased effectiveness of the explosive. The effect of the added risk should not be underestimated — bombing is an attractive crime because of the low risks currently associated with it. If these risks escalate, then the attractiveness decreases, probably resulting in significantly reduced numbers of bombings and significantly reduced severity of the bombings. Domestic and foreign law enforcement officials were emphatic in their opinions that increasing bomber risk was a valuable and important control mechanism.

In a similar vein, the importance of reducing the effectiveness of bombs should not be overlooked. Taggants have their optimum effectiveness in the protection of high-value targets and the investigation of significant bombings. It is in just those types of situations that reducing the effectiveness of bombs will have the most payoff.

Nevertheless, effective countermeasures are possible. Bombers with sufficient skill and training can completely overcome the effects of a taggant program if they have adequate time and resources. The greater the sophistication of the bomber, the smaller the risks and the smaller the loss of effectiveness resulting from countermeasures.

However, it should be recognized that while the countermeasure responses are entirely possible, it is by no means certain that significant numbers of bombers will actually use them.

OTA consulted numerous explosives experts, all of whom agreed that countermeasures such as those described were possible, at least for some of the types of criminal bombers. However, the law enforcement experts and experts on terrorism which OTA consulted also unanimously agreed that most criminal bombers, including terrorists, would fail to make use of the countermeasures. This assessment appears to be based on an assessment of the type of personality that is generally involved in bombings, as well as the general level of skill of the bombers. An instructive analogy is aircraft hijacking. It is possible to smuggle a weapon on an aircraft by a number of means, but in fact, since the antihijacking program started, there have been thousands of weapons found annually by the screening process, hundreds of weapons found abandoned near the controlled boarding gates, but essentially no cases of aircraft hijacked with the use of smuggled weapons.

FOREIGN EXPERIENCE IN CONTROL OF BOMBERS

Discussions were held with British, West German, and Irish law enforcement officials in an attempt to gain insight into the methods used to combat and control criminal bombings in those countries. The bombing problem in those countries, and most of the rest of Europe, is considerably different than the domestic problem; it is appropriate that the control methods also differ.

Essentially all bombings committed in the three countries are carried out by terrorists. In Britain and Ireland the bombings are almost entirely by one group of separatist terrorists — the IRA.

Commercial explosives are rigidly controlled in all three countries. In West Germany this control is primarily administrative— permits are needed for the transportation, storage, and use of explosives. In addition, a much more intensive surveillance of suspected criminals is practiced, together with a very intensive intelligence operation and a relatively strict border inspection procedure. As a result, almost all explosives used in bombings are homemade (85 percent), although some military and commercial explosives are used. The military explosives are stolen from military bases or recovered from maneuver areas, while the commercial explosives and detonators appear to come primarily from Eastern Europe.

In Ireland and Britain the controls are more direct. Commercial explosives are stored, transported, and maintained by the army or police, who personally supervise the detonators and check to ensure that no undetonated explosive remains in the area. The army or police has accountability for the explosives extends to the individual detonators and sticks of explosive. As a result, almost all criminal bombings use homemade explosives.

The number of bombing incidents per year in West Germany is about one-fourth of the number of domestic bombings reported to the FBI or BATF data banks, which results in about the same bombing rate on a population basis but a far higher rate per unit area, since West

Germany is about the size of Oregon. This geographic concentration, the single class of bombers, the almost universal use of homemade explosives and an effective centralized criminal control authority have allowed the West Germans to develop field and laboratory investigative techniques that apparently result in higher arrest and conviction rates than is the case in the United States.

The number of bombings in the Republic of Ireland is quite low; no data was available concerning numbers of bombings in Britain or arrest and conviction rates in either country.

The British use a tagging system that apparently consists of different colored threads interspersed in the explosive. The threads do not survive the detonation, but the system cannot be defeated by simply discarding the cartridge as can the current U.S. date-shift code. The West Germans use a system similar to the date-shift code, while the Irish dye their explosives (from the single plant) to indicate a destination.

The experience of these three countries offers some insight into the problem of control of domestic bombers and to potential bomber countermeasures.

As a result of law enforcement efforts to control the source of commercial explosives and to institute other efforts to combat bombers, there are essentially no bombers other than terrorists in any of the three countries. Given the different conditions in the United States, it is improbable that all other bombers would be eliminated, but their relative numbers could be expected to decline dramatically if a taggant program were implemented.

As a result of the control of commercial explosives, bombers in the three countries rely largely on homemade explosives. As noted earlier, this countermeasure is likely to be seen in the United States as well if a taggant program is initiated. The result of this shift in explosives will eliminate some bombings, make some targets difficult to attack due to decreased effectiveness of the explosives and significantly increase the risk of an accident to the perpetrator.

Finally, a possible long-term effect of the taggant program, as is the case in Europe due to explosives controls, may be the development of a highly skilled group of bombers, as well as more coordination and cooperation between bomber groups.

APPENDIXES

A—Letter of Request
B—Detection and Identification Taggants and Criminal Bombings—Summary and Questionnaire
C—OTA Recovery Tests
D—Products Liability Implications of Legally Requiring the Inclusion of Taggants in Explosives
E—Suitability of ANFO as a Filler for Criminal Bombs
F—Derivation of Bombing Statistics Tables
G—Glossary

APPENDIX A—LETTER OF REQUEST

ABRAHAM RIBICOFF, CONN., CHAIRMAN

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UNITED STATES SENATE
COMMITTEE ON
GOVERNMENTAL AFFAIRS
WASHINGTON, D.C. 20510

May 7, 1979

The Honorable Morris K. Udall
Chairman
Technology Assessment Board
Office of Technology Assessment
U. S. Congress
Washington, D. C. 20510

Dear Mo:

As you know the Committee on Governmental Affairs is presently considering S. 333 the Omnibus Antiterrorism Act of 1979. Section 303 of the legislation would mandate the use of identification and detection taggants in explosive materials.

During the course of our consideration of the bill, several issues have been raised pertaining to the viability and cost of the tagging program. While there has been a great amount of technical research in this field, we believe it would be useful to have an independent review and evaluation of the available data concerning the use of explosive taggants.

Specifically, we request that the Office of Technology Assessment review this data, and address the following issues:

- the safety of the use of taggants in production, storage, and handling of explosive materials;
- the effectiveness of the tagging program in deterring crime and aiding in criminal investigation and prosecution;

The Honorable Morris K. Udall May 7, 1979
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- the regulatory impact of requiring the use of explosives taggants (including record-keeping, cost to the explosives industry, and cost to the consumer);
- the potential effects of a partial application of tagging requirements (such as excluding black and smokeless powders and including all other explosive materials, excluding military, and materials for homemade bombs and common nitrate),
- the issues relating to the survivability of taggants, including effects of detonation, retrieval, and possible removal before detonation, and
- possible alternatives to tagging explosives and initiators

Because of the Committee's tight schedule and the desire to enact comprehensive anti-terrorism legislation promptly, we would appreciate receiving a report from OTA not later than August 6 1979

Many thanks for your cooperation and assistance

Sincerely,

Abe Ribicoff Jacob Javits

APPENDIX B—DETECTION AND IDENTIFICATION TAGGANTS AND CRIMINAL BOMBINGS—SUMMARY AND QUESTIONNAIRE

This paper is a short statistical summary of an empirical survey conducted by OTA for the evaluation of taggant effectiveness.

Using a listing of the International Association of Chiefs of Police, a systematic sample of 960 names was selected (from a total of 19,960 names on the list). Each of the subjects sampled—assumed to be both knowledgeable and interested in the problem of bombings — received a mail questionnaire covering five related areas of inquiry (see attachment). The questions probed issues such as the profile of the criminal bomber, the estimated effects of the taggants program on deterrence, detection, and conviction, and preferred location and types of detection taggants sensors.

Of the 960 questionnaires mailed out, only 114 have been returned in time for this analysis, a return rate of less than 12 percent. No assumption can be made that these 12 percent of the respondents are a random and unbiased subsample of the 960 subjects in the original sample, and most likely they represent the people most highly involved in and motivated to deal with criminal bombings. In that sense, the findings of this analysis must be viewed as tentative. However, these 114 questionnaires serve as a valuable instrument to bring to light some of the experiences, attitudes, and assessments of people who deal often on a rather frequent basis with criminal bombings. A further source of error may have been introduced by an error in the explanatory material accompanying the questionnaire. That material indicated that the taggant trace would identify the last legal purchaser rather than indicating that the trace would provide a list of the last legal purchasers. Following is an overview of their responses.

Background of Subjects

Over half (51 percent) of the subjects worked in an urban area, with an additional 37 percent in suburban areas. The majority (47 percent) came from relatively small cities (population up to 25,000) with only 20 percent from metropolitan areas with a population of 500,000 and more. Due to a lack of significant differences between the subjects by place of work, and due to the relatively small number of respondents, the data will not be analyzed by the type of area and the population size.

Bomber Profiles

As estimated by the sample, a wide variety of criminal bomber types, rather than one specific type, is responsible for the total number of bombings in their jurisdictions (table B-1). Eighty-five percent of the sample thought that each type of bomber is encountered infrequently (accounting for only up to 25 percent of the bombings). Domestic terrorists, organized crime figures, and people motivated by revenge were mentioned as somewhat more frequent types (between 25 to 75 percent of the cases) and, most noticeably, revenge was seen more than any other motive as a very frequent (over 75 percent) motivation for bombings.

Similarly, the consensus of the sample was that there is a fairly evenly distributed use of the various types of explosives (table B-2). While ANFO, plastic explosives, and cast or pressed military explosives were thought to be infrequent, there was less agreement about the other types. Commercial explosives, smokeless and black powders, and to a lesser degree, homemade explosives were mentioned by the subjects as frequently and even very frequently used in bombings in their areas.

A potentially important question refers to the various bomber types and their preferences for types of explosives (table B-3).

While, again, in general, the various bombers still use all the available explosives, when looking only at the "frequent" and "very frequent" use of those explosives, an interesting preference profile emerges: all offenders show a preference for commercial explosives and black and smokeless powder, but their highest use is by offenders acting out of revenge. Terrorists and organized crime use commercial explosives more often, while people committing crimes of passion or revenge opt more frequently for the powders.

An issue of some importance is the target of the bombing. As indicated by the sample (table B-4), bombers attack a variety of targets; however, there are some patterns in the attacks. Government and law enforcement facilities, transportation facilities, and residences are mostly infrequent targets, while commercial and industrial facilities, people, and vehicles, and schools are very frequent targets.

Some patterns emerge when looking at the target-preference of the various bomber types (table B-5). Combining the "frequent" and "very fre-

Table B-1.—Types of Criminal Bombers (percent)

	Bomber type							
	International terrorists	Domestic terrorists	Organized crime	Psychopaths	Crimes of passion	Revenge/disgruntled employee/malicious mischief	Others	Total
Infrequent	93. %	53.	86	93	96	58.	90	(32[illegible]) 84
Frequent	0	7		5.	2	11.	5	(23) 6
Very frequent	2	18.	3	2	2	30	5	(37) 10.
Total	(58) 16.7	([illegible]) 5.2	(51) 14.7	(59) 15.5	(54) 14.2	(79) 20.5	(20) 5.2	381

Based on pl... Q.
Infrequent = between 0 to 25 percent. Frequent = 25 to 75 percent. Very frequent = 75 to 100 percent.

Table B-2.—Types of Explosives Used (percent)

	Explosive type								
	Commercial	ANFO and other noncap-sensitive explosives	Plastic explosives	Cast or pressed military explosives	Smokeless powder	Black powder	Homemade materials	Other	Total
Infrequent	59 %	96	97	90.	98	82	83.	95.	(445) 79.9
Frequent	21	4	3.	6	2	13	12	0	(65) 11.7
Very frequent	20	0	0.	[illegible]	[illegible]	10.	5.	5	(47) 8.4
Total	([illegible]) 4.5	(18) 2.2	(68) 12.2	(71) 12.7	(73) 13.1	(81) 14.5	(75) 13.4	(41) 7.4	557

Based on pl... Q. 8.
Infrequent = between 0 to 25 percent. Frequent = 25 to 75 percent. Very frequent = 75 to 100 percent.

Table B-3.—Most Frequently Used Types of Explosives by Type of Bomber (percent)

	Bomber type					
	Terrorists	Organized crime	Psychopaths	Crimes of passion	Revenge, etc.	Total
Commercial	15. %	82	18	24	53.	(281) 33.
ANFO	1	0	1	1.	0	(257) 0.
Plastics	2	2.	4	2	3.	(266) 2.
Military explosives	8	8.	4	2	4.	(262) 6.
Black and smokeless powder	13	11	17	29	46	(276) 27
Total	289	265	300.	256	282	1,388

Based on pl... Q. 29.
The percentages include for each cell the proportion of responses estimating a frequent use (over 25 percent) of the particular explosive by the particular type of bomber. The numbers in parentheses refer to the frequency of all responses within the cell.

Table B-4.—Types of Bombing Targets (percent)

	Type of target							
	Vehicles, people	Schools	Residences	Transportation facilities	Commercial/industrial facilities	Gov't, law enforcement facilities	Other	Total
Infrequent	73 %	77	83	96.	88.	91	93	(401) 82
Frequent	12	5.	12	3.	12	6	5	(42) 9
Very frequent	15.	15.	1		26.	3	2.	(47) 9
Total	(78) 15.9	(83) 16.9	(76) 15.5	(69) 14.	(76) 15.5	(71) 13.3	(42) 8.6	490

Based on pl... Q. 8.
Infrequent = between 0 to 25 percent. Frequent = 25 to 75 percent. Very frequent = 75 to 100 percent.

Table B-5.—Most Frequent Targets by Type of Bomber (percent)

	Bomber type					
	Terrorists	Organized crime	Psychopaths	Crimes of passion	Revenge, etc.	Total
Vehicles, people	11 % (56)	22 (51)	4 (47)	27 (56)	28 (56)	20.5 (263)
Schools	0 (56)	0 (50)	0 (48)	0 (49)	20 (56)	9.5 (268)
Residences	0 (56)	14 (49)	4 (50)	17 (52)	36 (56)	14 (262)
Transportation facilities	0 (51)	0 (49)	2 (5)	0 (50)	6 (5)	2.8 (252)
Commercial/industrial facilities	22 (51)	17 (52)	10 (50)	6 (51)	30 (54)	7.5 (268)
Government, law enforcement facilities	15 (47)	4 (49)	4 (47)	4 (48)	13 (59)	6 (267)
Other	0 (30)	3 (32)	0 (39)	0 (3)	5 (99)	3.5 (170)
Total	396	395	327	329	368	1,798

aBased on [illegible]

The percentages indicate [illegible]

quent categories, the most common targets for terrorists are commercial and industrial establishments followed by Government; organized crime focuses on people and vehicles, and industry and commerce; psychopaths, as expected, act more randomly, mainly victimizing residences; crimes of passion are directed against people and residences; and revenge bombings are directed against commercial and industrial facilities and people and vehicles. It appears that the preferences for targets follow an underlying assumption about the motivations of the various bomber types.

Thefts of commercial explosives, legal purchase, and homemade supply seem to be the most frequent sources of explosives, while import and military theft are the least frequent forms (table B-6).

The most frequent source of explosives for terrorists and organized crime is theft. People acting out of revenge, and psychopaths prefer homemade explosives; for crimes of passion the offender purchases explosives legally or prepares them at home (table B-7).

Finally, a question about the tagging program brought some inconsistent responses. In estimating the expected frequency of various sources by bomber after tagging went into effect, the sample predicted a large shift toward increased use of military (untagged) explosives through theft, and of homemade and imported explosives. However, they did not predict an appreciable decline in the theft of commercial (tagged) explosives, or their legal purchase (table B-8). Comparing tables B-7 and B-8, the sample predicted a minor shift for terrorists toward homemade explosives, and for organized crime and terrorists toward military theft, but few other discoverable patterns emerged.

In summarize, there seems to be a consensus about a wide range of motives for criminal bombings, as well as their targets, the explosives used, and their sources. The profile of the bomber and some characteristic patterns of his modus operandi that emerge are consistent with general predictions as to the behavior rationality and psychological motivation of such offenders.

Present Law Enforcement Effectiveness

As estimated by the sample, both the arrest and the conviction rates for criminal bombings are lower than those for all other crimes (table B-9).

Estimated Utility of Identification Taggants

When asked about the utility of the program, all respondents viewed taggants as a useful additional

Table B-6.—Source of Explosives Used (percent)

	Legal purchase	Theft of commercial explosives	Blackmarket purchase	Theft of military explosives	Homemade	Importation	Total
Infrequent	72 %	57	83	88	66	92	(309) 75.9
Frequent	11	23	2	6	9	2	(51) 12.7
Very frequent	7	20	5	3	4	4	(45) 11.4
Total	(76) 18.9	(71) 17.4	(83) 18.2	(88) 16.4	(72) 17.9	(85) 10.2	(402)

aBased on [illegible]

Infrequent: between 0 and 25 percent; Frequent: 26 to 75 percent; Very frequent: 76 to 100 percent.

Table B-7.—Most Frequent Sources of Explosives by Type of Bomber (percent)

Source of explosives	Bomber type Terrorists	Organized crime	Psychopaths	Crimes of passion	Revenge, etc.	Total
Theft of commercial explosives	30. % (44)	29 (45)	9 (45)	5. (44)	36. (49)	5.5 (227)
Theft of military explosives	20 (45)	9 (44)	5 (44)	2. (43)	9 (49)	8.4 (229)
Legal purchase	7 (45)	19 (45)	11 (44)	16. (45)	32. (50)	17.4 (236)
Black market purchase	8 (43)	10 (47)	2 (45)	5. (46)	11 (47)	9.5 (222)
Homemade	14 (44)	11 (44)	7 (49)	14. (48)	35 (55)	18 (232)
Importation	2. (44)	8. (48)	0 (44)	a (43)	2 (47)	2.2 (224)
Total	266	272	265	259	303	1 364

Based on pt. [illegible] Q. 4b.
The percentages indicate [illegible] the proportion of responses estimating a frequent use (over 25 percent) of the particular explosive, by the particular type of bomber. The numbers in parentheses refer to the frequency of all responses within cell.

Table B-8.—Estimated Most Frequent Sources of Explosive by Bomber Type, Following the Institution of Tagging Programs (percent)

Sources of explosives	Bomber type Terrorists	Organized crime	Psychopaths	Crimes of passion	Revenge, etc.	Total
Theft of commercial explosives	38. % (60)	61 (54)	22. (51)	17 (48)	30 (54)	35.4 (268)
Theft of military explosives	32 (43)	37 (38)	20. (49)	4 (36)	16 (52)	23.0 (229)
Legal purchase	14 (42)	10 (53)	25. (50)	25 (53)	20. (50)	19.2 (250)
Black-market purchase	27 (41)	22. (46)	19 (50)	4 (26)	19 (55)	18.7 (243)
Homemade	39 (41)	24 (49)	25. (51)	25 (38)	36. (51)	28.6 (256)
Importation	29 (42)	24. (5)	6. (49)	2 (36)	6. (51)	13.[illegible] (242)
Total	247	261	264	304	331	1,477

Based on Pt. [illegible] Q. 8.
The percentages indicate [illegible] the proportion of responses estimating a frequent use (over 25 percent) of the particular explosive, by the particular type of bomber. The numbers in parentheses refer to the frequency of all responses within the cell.

Table B-9.—Estimated Rates of Arrest and Conviction

Estimated rates of arrest	
For criminal bombings	24.66
For other crimes	36.05
Estimated rates of conviction	
For criminal bombings	34.25
For other crimes	60.22

Based on pt. II-5.
NOTE: SATP considers these estimates unduly optimistic. At present, [illegible] of criminal bombings are forwarded for prosecution.

cies in investigation and conviction, though they estimated it to increase arrest rates most noticeably for offenders acting out of revenge or passion and having very little effect on the arrest of terrorists (table B-10).

As for the deterrent value of taggants, it was viewed to be most effective for those acting out of revenge and least effective, as expected, for psychopaths (table B-11).

In response to a tagging program, some countermeasures by the bombers are expected. For example, the sample estimated that if packaged explosives would be tagged but black and smokeless powders would not, an average of 55 percent of the bombers would shift to using powders.

Table B-10.—The Estimated Increase in the Arrest Rate for Criminal Bombers Due to the Use of Identification Taggants

Types of bombers	Increase in arrest rate Up to 25%	Up 25-75%	Up over 75%	Total
Terrorists	79 %	5	6	63
Organized crime	74.	3.	13.	54
Psychopaths	69	9.	21	53
Crimes of passion	53.	23.	24	55
Revenge, etc.	44.	30	26.	5[illegible]
Total	(171) 61.0	(64) 20.5	(50) 18.1	278

Based on pt. II

Table B-11.—The Estimated Deterrent Effect of Identification Taggants on Criminal Bombers

Type of bombers	Magnitude of deterrent effect Up to 25%	Up 25-75%	Up over 75%	Total
Terrorists	86. %	11	3	55
Organized crime	75.	17	11	60
Psychopaths	79	16	5	56
Crimes of passion	75.	14	11	51
Revenge, etc.	54	27	19	63
Total	(211) 72	(52) 7.8	(32) [illegible]	292

Based on pt. II Q. 4

The main consensus of the sample was that professional bombers (terrorists and organized crime) would be more likely to work on some countermeasure than would the nonprofessional offenders. The first two types would most likely shift to other kinds of explosives (not tagged) or remove the taggant if it required a reasonable amount of work. However psychopaths and people motivated by passion or revenge were predicted most likely to do nothing in response to the taggants (table B-12). The most frequent countermeasure overall was shifting to another type of explosive and the least frequent one was the removal of the taggant if it involves 10 hours of work.

Estimated Utility of Detection Taggants

Tagging explosives would have, as estimated by the respondents, a varying deterrent effect depending on the type of bomber. It would be most effective for those acting out of revenge or passion, least effective for psychopaths and terrorists (table B-13).

Taggants were also viewed as being instrumental in the direct or indirect apprehension of the bomber. It was estimated to lead most frequently to apprehension of the nonprofessional offenders (i.e., psychopaths, crimes of passion, and revenge) as expected (table B-14).

Table B-12.—The Most Frequent Predicted Change in Tactics by Type of Bombers, Due to the Use of Identification Taggants[a] (percent)

	Bomber type					
Change in tactics	Terrorists	Organized crime	Psychopaths	Crimes of passion	Revenge etc.	Total
Taggant removal (if simple)	40 % (47)	35 (42)	10 (44)	11 (44)	17 (46)	24.5 (224)
Do nothing	30 (45)	37 (46)	49 (45)	52 (46)	47 (35)	44.2 (238)
Taggant removal (if hard)	23 (43)	22 (41)	10 (42)	18 (9)	9 (84)	14.7 (211)
Shift to other explosive	59 (42)	58 (45)	38 (44)	33 (41)	46 (47)	46.6 (219)
Shift to other unlawful activity	19 (42)	32 (40)	13 (40)	25 (38)	34 (47)	22.0 (209)
Total	210	215	215	213	226	1 001

[a] Based on pt II 2.

The percentages indicate the proportion of respondents selecting a frequent rate (over 25 percent) of the particular explosive by the particular type of bomber. The numbers in parentheses refer to the frequency of all responses within the cell.

The most effective sensor to deter and apprehend bombers was judged to be the portable one requiring no special operator (table B-15). The other three types were viewed as considerably less effective, especially the stationary, specially operated sensor.

Detection taggants are also expected to prompt a variety of countermeasures by the potential bombers (table B-16). The more frequently used measures, as estimated by the sample, would be shifting to other explosives (untagged), removing the taggant or sealing the package if it is relatively easily accomplished. Terrorists and people acting out of revenge showed a slight preference for the first form, organized crime offenders for the sea

Table B-13.—The Estimated Deterrent Effect of Detection Taggants on Criminal Bombers[a]

	Magnitude of deterrent effect			
Type of bomber	Up to 25%	Up 25-75%	Up over 75%	Total
Terrorists	85 %	9	6	49
Organized crime	72	9	10	58
Psychopaths	90	6	2	59
Crimes of passion	75	10	19	47
Revenge etc.	54	41	5	67
Total	(240) 75	(49) 15.3	(34) 9.7	329

[a] Based on pt V Q 1.

Table B-14.—The Estimated Increase in the Arrest Rate for Criminal Bombers Due to the Use of Detection Taggants[a]

	Increase in arrest rate			
Type of bomber	Up to 25%	Up 25-75%	Up over 75%	Total
Terrorists	72 %	21	7	80
Organized crime	74	9	7	56
Psychopaths	80		6	
Crimes of passion	49		24	
Revenge etc.	41	32	27	73
Total	(190) 66.2	(74) 25.2	(32) 8.6	303

[a] Based on pt V Q 2.

Table B-15.—The Estimated Deterrent Effect of Detection Taggants by Type of Sensors Used[a]

	Magnitude of deterrent effect			
Type of sensor	Up to 25%	Up 25-75%	Up over 75%	Total
Stationary with skilled technicians	58 %	22	20	59
Portable with skilled technicians	41	30	34	59
Stationary, no need for skilled technician	50	28	28	60
Portable, no need for skilled technicians	28	25	43	65
Total	(131) 55.7	(69) 28.9	(52) 25.8	249

[a] Based on pt V Q 3.

Table B-16.—The Most Frequent Indicated Change in Tactics by Type of Bomber Due to the Use of Detection Taggants (percent)

	Bomber type					
Change in tactics	Terrorists	Organized crime	Psychopaths	Crimes of passion	Revenge, etc.	Total
Taggant removal; special knowledge equipment required	33 % (46)	33. (42)	7 (26)	8 (34)	17 (43)	24.8 (194)
Taggant removal with relative ease	5 (61)	51 (43)	26 (33)	20 (36)	27 (44)	25.9 (206)
Shift to other explosives	63 (47)	45 (53)	24 (42)	6 (36)	36 (45)	37.8 (217)
Shift to target less likely to have sensors	43 (44)	24. (38)	3 (38)	18 (34)	27 (44)	25.1 (198)
Shift to other unlawful activity	26 (40)	26. (38)	9 (35)	1 (38)	21 (47)	17.8 (193)
Do nothing	27 (37)	50 (37)	34. (38)	27 (36)	29 (38)	29.4 (186)
Total	248	252	225	232	237	1 194

SOURCE: OTA

The percentages indicated are for the proportion of responses indicating a frequent (over 25 percent) of the particular response by the particular type of bomber. The numbers in parentheses refer to the frequency of all responses within the cell

and Psychopaths and crimes of passion were judged to be unaffected.

Finally the sample was asked to recommend the four sensor types (based on cost) for the various target locations (table B-17). Overall the most frequently recommended type was the portable and less expensive sensor (33 percent), and the most frequently mentioned locations to be protected were nuclear power stations and airports (both 14.8 percent). The only location for which the portable expensive sensor was more often (31.4 percent) recommended was nuclear power stations. The expensive nonportable sensor was suggested to any appreciable degree for use only for airports, large Government buildings, and nuclear powerplants while the less expensive portable set was the overwhelming preference for small Government buildings, schools, public stadiums, buses, and police stations. Apparently the respondents based their recommendations on cost factors, coupled with the frequency and likelihood of attacks and damage on the various locations.

Summary

Even though the response rate to the mail questionnaire was low, resulting in a small and statistically nonrepresentative sample, some valuable findings emerged from the study.

In the assessment of the respondents, criminal bombings are characterized by a heterogeneity of all the elements involved: a variety of bombers, different kinds of targets, a choice of explosives and a wide offering of sources to obtain them. No one kind of bomber is overwhelmingly responsible for a majority of the bombings; bombers do not concentrate on one type of target or use one type of explosive. However, within this complex picture some patterns are discernible. Certain types of bombers show a preference for certain targets, explosives, and sources. Depending on their motivations, the various bomber types are also expected to respond differently to the proposed taggant program. While the sample in general estimated taggants to reduce bombings (by deterrence, appre-

Table B-17.—Type of Sensors Recommended by Location

	Sensor type				
Location	Portable cost $15,000	Portable cost $50,000	Nonportable cost $15,000	Nonportable cost $250,000	Total
Airports	26.7%	24.8	25.6	[illegible]	(121) 9.3
Large Government buildings	29.5	27.5	8.4	24.6	(95) 12.
Small Government buildings	53.8	14.1	24.4	7.7	(78) 9.5
Nuclear power stations	23.6	31.4	8.5	28.4	(121) 10.8
Schools	63.0	12.1	3.6	1.6	(58) 6
Public stadiums	59.2	21.5	10.5	3.8	(76) 9.7
Bus, train depots	56.8	11.1	27.8	4.2	(72) 8.8
Large commercial buildings	42.2	18.0	28.2	11.9	(7) 8.7
Police bomb investigation	57.4	31.5	6.5	4.8	(6) 13.2
Nonuse no ability	25	0	75	0	4 .5
Total	(360)	(86)	(87)	(112)	881
	44.	22.7	0.0	3.7	

SOURCE: OTA

[illegible] considerable difficulty in obtaining untagged explosives, etc.) there is evidence in their views that the taggants will be more effective with certain bomber types than with others. In addition the taggants were also predicted to initiate a chain of countermeasures, with varying degrees of probable success.

In summary, the study points to some new directions in appraising the present scene of criminal bombings, and evaluating taggant effectiveness. The accuracy of the findings, which point to the hypothesized direction, should increase their validity and the confidence in their suggestive value though the methodological sampling problems prevent the study from serving as a definitive verifying answer to the issues researched.

QUESTIONNAIRE

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Congress of the United States
OFFICE OF TECHNOLOGY ASSESSMENT
WASHINGTON, D.C. 20510

JOHN H. GIBBONS
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The Congress has before it draft legislation which would require the addition of detection and identification taggants to commercial explosives. Detection taggants are material which would be detected by a suitable sensor to indicate the presence of explosives. Identification taggants are material which would survive the explosive detonation and provide information which would identify the last legal purchaser of the explosive used. The Bureau of Alcohol, Tobacco, and Firearms Control (BATF) has been supporting the development of taggants for the past several years. Testimony before the Congress has displayed a considerable diversity of opinion as to the utility, cost and safety of a taggant requirement.

At the present time considerable progress has been made in identification taggants research. Small plastic chips, consisting of several pigmented layers, have been developed by 3M which survive the detonation of most commercial explosives. The sequence of the pigmented layers provides the code to trace the explosives type, the manufacturer and time of manufacture. A record keeping network, by which the manufacturers, distributors, and retail sellers keep track of the code species would then allow law enforcement officials to trace the last legal purchaser of the explosives used in a bomb.

Research is less advanced on detection taggants. A number of approaches are being pursued. The best system so far developed consists of microencapsulated organic liquids which emit a distinctive vapor, coupled with a sensor tuned to detect those specific taggant molecules at a parts per trillion concentration level.

The Office of Technology Assessment has been asked by the Congress to analyze the proposed legislation and resolve the differences surfaced in the congressional testimony. Your response to the enclosed questionnaire is being sought as a part of the analysis of the utility of taggants. The questions bear on the issues of the profiles of the criminal bomber and the impact the proposed program would have on the efforts of law enforcement personnel to deter, apprehend, and convict criminal bombers.

The results of the study must be available to the Congress when it returns from the August recess. Would you therefore please fill out the enclosed material and return it as soon as possible. The information about where you work is necessary for demographic analysis; all individual replies will be treated as confidential information.

In answering the questions below, your estimates would be appreciated where data is not available. Please feel free to comment on any point of the questionnaire.

Indicate the approximate range of your answers by the following code:

A	almost none 0-5%
B	infrequently 5-25%
C	frequent or usual 25-75%
D	very frequent 75-95%
E	Almost always 95%-100%

DATA BASE (Where you Work)

I Population of city or county________________________

state________________

Check one urban area_____ suburb_______ rural _____

II Bomber Profiles

1 Type of Criminal Bombers The term criminal bomber" can cover a large spectrum of types of bombers What type would you estimate is responsible for the bombings in your area over the last **4-5 years**

International terrorists _____

Domestic terrorists _____

Organized crime _____

Psychopaths _____

Crimes of passion _____

Revenge disgruntled employess malicious mischief _____

Others (   ) _____

2 **Types of explosives** used in bombs A variety of materials can be used as explosives How often are the following explosives used in your area

Commercial explosives such as dynamites water gels _____

A NFO or other non cap sensative explosives _____

Plastic explosives such **as C-4** _____

Cast or pressed military explosives such as Composition B TNT RDX _____

Smokeless powder _____

Black powder _____

Homemade materials _____

Others _____

Please estimate how often each type of bomber in your area uses each type of explosive

	Commercial Explosives	ANFO	Plastics	Military Explosives	Black and Smokeless Powder
Terrorists					
Organized Crime					
Psychopaths					
Crimes of Passion					
Revenge Disgruntled employees malicious mischief					

3 Targets

Please indicate the frequency with which each type of target is attacked by criminal bombers in your area

Vehicles or people _____

Schools _____

Residences _____

Transportation facilities _____

Commercial Industrial facilities _____

Government law enforcement facilities ____

Other ____

Please indicate approximately how frequently each type of bomber in your area attacks each type of target

	Vehicles, People	Schools	Residences	Transportation Facilities	Commercial, Industrial	Government, Law Enforcement	Other
Terrorists							
Organized Crime							
Psychopaths							
Crimes of Passion							
Revenge Disgruntled Employees malicious mischief							

4 Sources of Explosives

Please indicate the relative frequency of each of the following as a source of supply of explosives for the criminal bombers in your area

Legal Purchase ____

Theft of commercial explosives ____

Blackmarket Purchase ____

Theft of military explosives ____

Home made ______

Importation ______

Please estimate the relative frequency of the various sources for each group of bombers in your area.

	Theft, Commercial Explosives	Theft, military explosives	Legal Purchase	Black Market Purchase	Home-made	Importation
Terrorists						
Organized crime						
Psychopaths						
Crimes of Passion						
Revenge Disgruntled Employees malicious mischief						

5 If explosives were tagged would you expect bombers to alter their pattern of acquiring explosives? Please estimate the expected relative frequency of the various sources for each type of bomber in your area if a tagging program were instituted (military explosives would not be tagged)

	Theft, Commercial Explosives	Theft, Military Explosives	Legal Purchase	Black Market Purchase	Home made	Importation
Terrorists						
Organized Crime						
Psychopaths						
Crimes of Passion						
Revenge Disgruntled Employees malicious mischief						

III Law Enforcement Effectiveness at Present

1 In answering the following questions, please estimate to the nearest 10%

a What is the rate of arrests for criminal bombings _____
b What percent of arrested bombers are convicted _____
c What is a typical arrest rate for other crimes _____
d What is a typical conviction rate for other crimes _____

IV Estimated Utility of Identification Taggants

1 Would the use of identification taggants provide a useful additional clue in an investigation of criminal bombings? _____

Comment

2 In your estimation, would the use of identification taggants lead to an increase in the arrest rate for criminal bombers?
Please estimate for each type of bomber in your area

Terrorists _____
Organized Crime _____
Psychopaths _____
Crimes of Passion _____
Revenge Disgruntled Employees Malicious Mischief _____

Comment

3 Would the use of identification taggants lead to increased conviction rates for criminal bombers? _____
Comment

4 Would knowledge of the fact that identification taggants are used in explosives deter criminal bombers? Please estimate for each type of bomber in your area.

Terrorist _____

Organized Crime _____

Psychopaths _____

Crimes of Passion _____

Revenge Disgruntled Employees Malicious Mischief _____

Comment:

5 Some people have proposed tagging packaged explosives but not tagging black or smokeless powder. If this were done approximately what proportion of the bombers who now use packaged explosives would shift to using powder to make bombs? __________

6 Countermeasures.

The use of identification taggants in explosives could alter the current method of operation of criminal bombers. Please estimate how likely each of the indicated change in tactics would be for each of the types of bombers encountered in your area

	Terrorists	Organized Crime	Psychopath	Crimes of Passion	Revenge Disgruntled Employees, Malicious Mischief
Taggant removal, if removal takes 1 hour per pound of explosives					
Do nothing					
Taggant removal if removal takes 10 hours per pound of explosives					
Shift to another type of explosives (foreign, stolen, home made)					
Shift to another type of unlawful activity					

V. Utility of Detection Taggants

1 Would knowledge of the fact that detection taggants are used in explosives deter criminal bombers? Please estimate for each type of bomber in your area

Terrorists ______
Organized Crime ______
Psychopaths ______
Crimes of Passion ______
Revenge Disgruntled Employees malicious mischief ______

2 How frequently would the use of detection taggants in explosives lead to the arrests of criminal bombers either through direct apprehension of a bomber with explosives in his possession or through an indirect means such as a clue being provided by a bomb discovered unexploded? Please estimate for each type of bomber in your area

Terrorists ______
Organized Crime ______
Psychopaths ______
Crimes of Passion ______
Revenge Disgruntled Employees malicious mischief ______

3 A number of types of sensors are being investigated for use in conjunction with the detection taggant source Please indicate the frequency with which criminal bombers are likely to be detered or apprehended due to the use of detection taggants coupled with sensors possessing the following characteristics

Stationary installation only must be operated by a skilled technician ______

Sensor is easily portable (can be used also in a fixed installation) must be operated by a skilled technician ____

Stationary installation only requires no special operator only someone in the area to react to an alarm or other simple indicator ____

Sensor is easily portable requires no special operator ____

4 Counter measures

The use of detection taggants in explosives could alter the current method of operation of criminal bombers Please estimate how likely each of the changes in tactics would be for each type of bomber in your area

	Terror	Organ. Crime	Psychopaths	Crimes of Passion	Revenge, Disgruntled Employees, Mischief
Package seal or taggant removal if specialized knowledge and equipment is required					
Package seal or taggant removal if relatively easily accomplished					
Shift to another type of explosive (Foreign, stolen, home made)					
Shift bombings to targets less likely to have sensors					
Shift to another type of unlawful activity					
Do Nothing					

5 Sensor Location

Please indicate the location where you believe detection sensors should be placed For this question simply check all locations appropriate for each cost and portability category.

	Sensor portable Cost - [illegible]	Sensor portable Cost - $50,000	Sensor - non-portable Cost - $15,000	Sensor - non-portable [illegible] 2[illegible]
Airports				
Large Government Bldgs.				
Small Government Bldgs				
Nuclear Power Stations				
Schools				
Public Stadiums, arenas				
Bus, train depots				
Large Commercial Bldgs				
Police Bomb investigators				
None, No Utility				

* Sensors to be used by investigators in searching for bombs

Introduction

As indicated in chapters II and III, a number of tests, demonstrations, and training exercises have been conducted by BATF, the Aerospace Corp., both 3M, RON, the local police departments and others in which attempts were made to recover the 3M identification taggants from the postdetonation debris. These tests usually had limited objectives, such as demonstrating that taggants could be found by trained law enforcement personnel. As a result, little or no control was placed on the tests and little or no documentation was attempted. As an example, BATF conducts 2-week training courses at its academy at Glynco, Ga. Over 50 test bombings of automobiles have been conducted with tagged explosives as part of that training exercise, but no data has been collected on recovery.

Due to the different aims, purposes and procedures, some similar tests conducted by different groups resulted in widely varying recovery rates. As an example, table 11 of chapter II shows that BATF and Aerospace were able to recover taggants from automobile bombing demonstrations under both relatively benign and very adverse conditions. In similar LME tests, shown in table 12 of chapter II, difficulty was encountered in recovering taggants from automobile detonations even under benign conditions.

As none of the tests were well controlled or documented, it was extremely difficult to analyze the reasons for the differences or even quantify the recovery expectations under any conditions. OTA therefore accepted an offer by BATF to conduct a controlled series of tests under OTA control.

Test Objective

The objective of the test series was to obtain quantified data on the postdetonation recovery of the 3M identification taggants under relatively controlled test and recovery conditions. Such data would provide an indication of the recoverability of the taggants under these conditions (although probably not a statistically valid demonstration). It might also provide insight into recovery under other conditions and help to resolve the dichotomy of prior test results. It was originally hoped that tests could be run against a variety of targets, including buildings and automobiles. Due to time and fiscal constraints, however, it was necessary to limit the target to automobiles. Test facility restrictions limited the placement of the automobiles to unpaved surfaces; the surfaces used were hard-packed gravel-laden earth. Within the constraints it was hoped that the tests would resolve the following four specific questions:*

1. Is it reasonable to presume that sufficient taggants can be recovered from automobile bombings under realistic conditions to enable a determination to be made as to the origin of the tagged explosive? Even if taggants are recovered from each test condition, no more than a presumption of recoverability may be made. A more extensive testing program would be necessary to determine the conditions under which the taggants are recoverable. Parameters of a definitive test series would include weather, fire, fireman response, and between-test replication variability. Failure to recover taggants under each of the test conditions would lead to a presumption that the taggants could not be expected to provide information on the origin of explosives in car bombings. Success in some of the tests would indicate that information would presumably be available from a subset of automobile bombings; definitive testing would be required to precisely define that subset.
2. Are there conditions that are more likely than others under which automobile bombings will yield taggants sufficient to establish the explosive's source? The specific condition to be tested is the relative strength of the explosive. Test conditions may also permit a limited assessment of the effects on recovery of the skill or dedication of the investigator, the weather, and the effects of fire and subsequent firefighting efforts.
3. What is the magnitude of the effort necessary to recover sufficient postdetonation taggants for explosive source determination? If, in fact, heroic efforts are required (as was reportedly the case in one of the Aerospace/BATF tests) then the utility of taggants in automobile bombings would be limited to the bombings of high-value targets and would not be of value to routine investigations normally carried out by bomb squads. These limitations would apply only to those conditions under which heroic efforts were necessary. This question only has meaning if the taggants are, in fact, recovered, even after heroic efforts.

---

*These questions are quoted verbatim from a prepared testing document and have been modified only to reflect the unavailability of paved surfaces.

6. Are the taggants field readable? One of the advantages of the 3M taggants is their ability to be easily and quickly read by agents in the field. If, in fact, large amounts of debris must be collected and laboratory processed, then the taggants are not field readable, at least for those catastrophic bombings which are similar to the test conditions. If the 3M taggants are not field readable, then perhaps some of the other tagging methods rejected for that reason should be reconsidered.

Similarly, OTA believed that if taggants were not recovered in ample quantities in the tests, this would not necessarily indicate that taggants could not be recovered under more favorable conditions—for example, a bombing that damages but does not destroy a building. However, the presumption that taggants could not be recovered under some realistic conditions would affect OTA's analysis of the utility of taggants, and the greater the range of conditions in which taggants could not be recovered—or could be recovered only after heroic efforts—the greater the negative impact on estimates of taggant utility.

Test Conditions

Bombs, each consisting of approximately 2 lb of dynamite, were placed in five automobiles and remotely detonated. The automobiles were located on hard-packed, relatively level earth. Three were on dirt roads and two were on bare patches of hard-packed ground. No brush or debris was in the immediate vicinity of the automobiles. Specific test conditions are summarized in table C-1. By comparing the results of tests 1 through 3, it is possible to relate recovery to the power of the dynamite. By comparing the results of tests 1 and 4, it is possible to assess the effects of a fire and subsequent firefighting activities. By comparing tests 3 and 5, it is possible to assess the effects of the added confinement provided by the engine block.

The explosives for the tests were chosen by OTA from a larger inventory of factory-tagged explosives provided by the Aerospace Corp. A 0.05 percent concentration of encapsulated taggants was used in each case, except that in test 4 the explosive contained 0.05 percent of each of two separate unencapsulated taggants. The explosives were assembled into a bomb and covered with a brown bag by Dr. Edward James of the OTA analysis team and placed in the target by Dr. James with the assistance of a different FBI agent for each test; the FBI agents could not see the explosive cartridges. The choice of explosives and placement decisions were made by David Garfinkle and Dr. James, the OTA test coordinators, who were unknown to anyone else. Samples were removed from each bomb for analysis to ensure that taggants were, in fact, present in each type of dynamite and to validate the identity of the predetonation recovered taggants.

Recovery Procedures

An attempt was made in the recovery process to see if differences in training and experience resulted in differences in the probability of recovering taggants. To test the question of this recovery skill, two sweeps were made of each target. The first sweep was made by an "amateur" team to roughly simulate the procedure and skill that might be expected from a typical bomb squad. The second sweep was made by a trained BATF team. The amateur team in each case consisted of a member of the OTA study group, another non-BATF volunteer, and one BATF agent. The non-BATF volunteers, one to a team, included Randall Bowman of NRA, Robert Hodgdon of the Hodgdon Powder Co., Officer Larry Linville of the Washington Metropolitan Police Bomb Squad, and Dennis Allen, an FBI agent. The team was given approximately 5 minutes of instruction and 1 hour for the search. The searches of all but the firebombing test (test 4) were conducted between approximately 3 and 4 p.m., with the use of blankets, black lights, and magnetic brooms contained in the Aerospace Corp.-developed kits shown in figure C-1. The amateur teams searched for taggants with the black light, did a magnetic sweep, and collected debris for laboratory analysis.

Table C-1.—Specific Test Conditions, OTA Recovery Tests

Test	Placement	Dynamite	Test condition
1	Under driver's seat	Coalite C, low power	5-gal gas in tank, no fire
2	Under driver's seat	Unigel, medium power	5-gal gas in tank, no fire
3	Under driver's seat	Power Primer, high power	5-gal gas in tank, no fire
4	Under driver's seat	Coalite C, low power	[illegible]-gal gas adjacent to bomb, fire, firefighting
5	Between engine and firewall	Power Primer, high power	Dry tank, no fire

SOURCE: Office of Technology Assessment.

Figure C-1.—Portable Kits Developed by the Aerospace Corp. Were Utilized in the OTA Taggant Recovery Tests

Photo credit: U.S. Department of the Treasury

The six-man BATF professional teams then conducted a thorough second sweep of each target including further collection of debris, magnetic sweeping, and taggant black light search. For this search the area was divided into grids, and the collected material was carefully identified by the grid number. Figure C-2 shows the grid used in test 3. Each BATF search took approximately 5 hours.

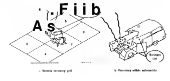
Laboratory Analysis

A preliminary analysis was conducted at the test site by a team from the BATF national laboratory. A few taggants were identified from the first three tests conducted (actually tests 5, 1, and 2) to demonstrate field laboratory identification. The material was then taken to the BATF national laboratory and quantitatively analyzed. The time necessary to recover more than 20 taggants for each test was recorded, as was the location of the debris from which the taggants were collected. The taggants were then mounted on slides and the codes read. Identification of the explosives was then made from the taggant code. Most of the laboratory analysis was conducted by Mr. Richard Strobel of the BATF national laboratory, although a volunteer team from NRA separated four of the taggants from the test 3 debris.

Test Results

The results of the tests are summarized in table C-2. Over 20 taggants were recovered in the laboratory from the debris of each automobile bombing. Laboratory time ranged from less than ½ hour to approximately 4 hours (plus 7 hours preliminary time to refine procedures). Taggants were recovered from the amateur sweep in three of the five tests. In one test, the amateur and professional sweep material became mixed up during transportation to the BATF national laboratory as a result of a deep chuckhole. In the last case, the amateur search material was inadvertently stored separately from the other recovered debris and not examined. Photomicrographs of the recovered taggants are shown in figures C-3 through C-7, one for each test. Some of the separated taggants from test 5

Figure C-2.—BATF Search Grid



a. General recovery grid

b. Recovery within automobile

Table C-2—OTA Recovery Test Results

Test	Condition	Number of taggants recovered	Source of taggants	Laboratory time (hours)
1.	Collins C low power under driver's seat	26	Amateur search	4
2.	Unigel medium power under driver's seat	23 + contaminant	Amateur search	4
3.	Power Primer high power under driver's seat	2 total 2 type A 0 type B	Unknown	4
4.	Collins C low power under driver's seat, fire, firefighting	23	BATF team primarily from automobile exterior and under automobile	8
5.	Power Primer high power, between engine and firewall	26 + contaminants (from tags from collection equipment)	Amateur search	4 hours + 6 hours (initial sixty time to define procedures. This was first material processed in laboratory

SOURCE: Office of Technology Assessment

Figure C-3—Recovered Taggants From Test 1 (low power)

Figure C-4—Recovered Taggants From Test 2 (medium power)

were accidentally brushed off the mounting. Slide/ other recovered taggants are shown.

No taggants were individually recovered in the field, recognized as such, and field read.

All the explosives were correctly identified by BATF as a result of the color code on the taggants. The letter from BATF to OTA which gives the identification information is shown as an attachment. The test nomenclature in the letter differs from that used in text. The letter refers to the scenes in chronological order. In the text the tests have been grouped for ease of comparison. The following conversion of the letter "scene" designation to the text "test number" designation is necessary:

Scene 1	Test 5
Scene 2	Test 1
Scene 3	Test 2
Scene 4	Test 3
Scene 5	Test 4

Figure C-5—Recovered Taggants From Test 3 (high power)

Figure C-6.—Recovered Taggants From Test 4 (low power)

Figure C-7.—Recovered Taggants From Test 5 (high power, containment)

Test Responsibility

[illegible]

bombs and placed the bombs in the target. (FBI agents inserted the detonators and initiated the explosions.) No one else knew which explosives were used on each automobile, or even which explosives from a larger selection were chosen. OTA, with assistance from NPA, observed the laboratory procedures and participated in the separation process.

BATF supplied the automobile targets, the test site, and the agents for field recovery and laboratory analysis of the taggants. The explosives were supplied by the Aerospace Corp.

IME was invited by OTA to participate in the test series. Due to the short time available for the test planning, IME was not able to fully participate. They did provide some valuable guidance, however, in a working session attended by OTA, BATF, SAAMI, NPA, and IME representatives.

Discussion of Results

Too few recovery tests of the 3M identification taggants were conducted under real-world conditions to allow a definitive judgment to be made of recovery. In addition, only one type of target, automobiles, was used in the tests. However, the ease with which taggants were recovered under the rather severe test conditions, indicates that taggants could be expected to be recovered under a wide range of bombing conditions, given the proper training and effort by field and laboratory investigators. A number of points should be made as a result of the test series.

In the first place, the taggants do not appear to be field recoverable and readable, at least under the test conditions. Approximately 25 people looked for taggants, for a total of approximately 35 man-hours in both daylight and nighttime conditions, without visually recovering a single taggant. This was the case even though taggants were easily recoverable from the debris in the laboratory. BATF operating procedure, which calls for visual search, is not only ineffective; it is counterproductive. Investigators are likely to become discouraged when they can't visually find a taggant and not collect samples for laboratory analysis. BATF procedures should stress the importance of the collection of debris for analysis. It has been claimed that the earth at the test site is unusually rich in magnetic materials and materials which fluoresce naturally, and that the tests were particularly severe from the visual recovery standpoint. Visual recovery may, in fact, be possible in situations such as an automobile bombing on a large paved area, or a small bomb in a large building. It appears likely, however, that taggants will be missed quite often if visual recovery means are emphasized.

The second point is that taggants appear to be recoverable from bombings with a modest data commitment effort on the part of field and laboratory personnel. Even under conditions of partial confinement, taggants from a high-energy dynamite were easily recovered. Similarly, taggants from a low-power dynamite were recovered even after a severe fire and firefighting activity. Additional tests would be required before the effects of full confinement, such as in pipe bombs, or before the effect of fire after a high-energy detonation, could be known. Similarly, no tests have been conducted with large charges, or with tagged boosters and detonators used to detonate an untagged blasting agent.

It appears that the power of the explosive does not significantly affect recovery probability or the laboratory time necessary to separate taggants from the debris. Confinement and the occurrence of fire, however, do significantly affect laboratory recovery time, as the size of the taggants decreases.

Some difficulty was encountered in reading the colors of the taggant layers, even by experts from 3M. The pigments currently available, however, have been substantially improved durability and lead to fewer errors in interpreting the code.

The tests were conducted and field recovery completed on three of the five tests under near ideal weather conditions. A light rain fell before debris was collected from two tests, however, including the associated Power Primer and the one in which a fire followed the detonation. The light rain did not appear to dampen recovery, even for these severe test conditions; a heavy rain might, however, have more effect.

It should be noted that the automobile tests conducted represent rather severe tests of recovery (at least neglecting confinement). It is reasonable to infer, therefore, that taggants could probably be recovered from building bombings, bombings in the open, and most other noncontained bombings.

It is interesting to note that no fires occurred as a result of the bombings when fuel was in the fuel tanks, even for the most powerful commercial explosive (excluding boosters). While a sample of three is hardly significant, the tests do indicate that fires do not occur as a matter of course in automobile bombings.

Finally, it should be noted that these tests provide a possible explanation of the wide divergence of prior test data. Most of the tests in which BATF/Aerospace recovered taggants involved a laboratory recovery procedure; this was particularly true for the severe automobile bombings. Most of the unsuccessful tests by IME and others have either not included laboratory analysis or have had the laboratory separation process conducted by people with no training in separating the taggants.

DEPARTMENT OF THE TREASURY
BUREAU OF ALCOHOL, TOBACCO AND FIREARMS
WASHINGTON, D.C. 20226

September 28, 1979

REFER TO:
DS: RD: NDW
7555

Mr. David Garfinkle
Office of Technology Assessment
600 Pennsylvania Avenue
Washington, DC 20510

Dear Mr. Garfinkle:

The following test results were obtained from the taggant survival studies conducted for you at Fort Belvoir, Virginia, on September 13, 1979.

Scene 1 was a 1949 Ford pickup truck. A 3- to 4-hour laboratory analysis of the bomb debris collected by Dr. Ed James (OTA), Mr. Randall Bowman (NRA), and Special Agent Marcus Davis (ATF) resulted in the isolation of 26 taggants bearing code F5959592M8. This identifies the explosives used in this case as Atlas Power Primer, size 1 1/4- x8" Date/Shift Code 01 12 77 R2. Many contaminate training taggants were also in portions of the bombing debris. These probably came from a single contaminated recovery kit. The red layer in this early pre-pilot test version of the 3M taggant contains an organic pigment, and noticeable variation in hue was observed. This problem has subsequently been corrected in later versions of the 3M taggants.

Scene 2 was a late model Ford Galaxy. A 1-hour, 20-minute laboratory analysis of the bomb debris collected by you, Mr. Robert Hodgdon (Hodgon Powder Company), and Special Agent Eugene Reagan (ATF) resulted in the isolation of 28 taggants bearing code F3913142M0. This identifies the explosives used in this case as a Hercules permissible dynamite, either Red HA, size 1-1/4 x 8", Date/Shift Code Jul 12 78 J1, or Collier C, size 1 1/4" x 8", Date/Shift Code Nov 21 78 J1. Both explosives were tagged with the same taggant code.

Scene 3 was an Oldsmobile station wagon. A 25-minute laboratory analysis of the bomb debris collected by Mr. Steve Kornish (OTA), Officer Larry Linville (Washington, DC Metropolitan Police Department), and

Special Agent Ivan Kalister (ATF) resulted in the isolation of 23 taggants bearing code F5989142M0 This identifies the explosives used in this case as Hercules Unigel Tube Shell, size 2" x 16" Date/Shift Code Jun 27 78 J1. One contaminate training taggant was also found in this debris

Scene 4 was a Chevrolet Malibu sedan. Twenty one taggants were recovered—17 by our laboratory's chemist in 45 minutes, and 4 by the NRA's observers, Ms. Susan Rogers and Mr. James Flechenstein, in an unspecified time Twelve of these taggants bear code F5986726M0, and 9 bear code F5984642M0 These taggants identify the explosives used in this case as Atlas Power Primer, size 1-1/4" x 8", Date/Shift Code 10-24-78-R2 This material was specially produced for The Aerospace Corporation by Atlas Powder Company with an unencapsulated taggant species of one code and a taggant of a different code from which the encapsulating material had been stripped by solvent action

Scene 5 was the Chrysler-product station wagon which was "fire-bombed" and permitted to burn until you directed the Fort Belvoir Fire Department to respond A 3 hour laboratory analysis of bomb scene debris collected during an 8-man 2-hour ATF search under the direction of Special Agent Eugene Reagan, resulted in the isolation of 23 taggants bearing code F3913142M0 This identifies the explosives used in this case as either Hercules Red HA, size 1-1/4" x 8", Date/Shift Code Jul 12 78 J1, or Collier C, size 1-1/4" x 8" Date/Shift Code Nov 21 78 J1, both with the same taggant.

These taggants and those mounted by Mr. Bowman of the NRA from field and first-day laboratory recoveries were given to you on September 24, 1979, for your use and examination If we can be of any further service to you in documenting the results of these tests, please contact me.

Sincerely yours,

W. David Williams
Explosives Scientist

APPENDIX D—PRODUCTS LIABILITY IMPLICATIONS OF LEGALLY REQUIRING THE INCLUSION OF TAGGANTS IN EXPLOSIVES

by James A. Henderson, Jr., Boston University School of Law
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3rd Year Law Student, Boston University School of Law
October 9, 1979

ANALYSIS OF EXPLOSIVES INDUSTRY'S EXPOSURE TO PRODUCTS LIABILITY UNDER EXISTING LAW

Limits and Purposes of the Present Analysis

The analysis in this section covers the exposure to civil liability for damages under existing law of 1) manufacturers and other commercial suppliers of explosives, 2) manufacturers and other commercial suppliers of components that go into the production of explosives, 3) manufacturers and other commercial suppliers of accessories ordinarily used with explosives, such as blasting caps and fuses, and 4) commercial transporters and users of explosives. The analysis does not cover the commercial suppliers of a range of products sometimes referred to by legal commentators as "explosives," including firearms and ammunition, vehicles and aerosol cans, fireworks and bottled beverages.

The term "products liability" includes all civil liability for damages arising out of injury to persons or property caused by unsafe, defective products, including liability based on theories of negligence, warranty, misrepresentation, and strict liability. "Products liability" does not include criminal liability or civil liability based on express contractual obligations other than express warranty. The phrase "exposure to liability" refers to the conceptual bases and limits of liability; the author does not have access to factual data relating to frequency of claims, payouts to claimants, availability of liability insurance, and the like in the explosives industry. The *Final Report* of the Interagency Task Force on Products *Liability* (Dep't. of Commerce, Oct. 31, 1977) indicates that the industrial chemicals industry, the closest industry to explosives in that study, is more often than not a leader in terms of the average number of new claims per firm per year. (See *Final Report*, table [illegible] 3.)

The main objective of this appendix is to examine the products liability implications of legally requiring the inclusion of taggants in explosives. Such examination can meaningfully be undertaken only in the context of an adequate understanding of the existing legal environment into which such a taggants requirement would be inserted. The analysis in this section should render such an understanding possible for those, including some members of Congress and their staffs, who may not be intimately familiar with the subject of products liability. A summary of the elements of this analysis is provided at the end of the section to facilitate review and quick reference.

The Major Doctrinal Bases of Liability

Negligence

Negligent conduct is conduct that is riskier than a reasonably prudent person would engage in. The mere fact that conduct creates risk does not make it negligent conduct. All human activities involve some risks of injury, and certain levels of risk are socially acceptable. Driving a car, for example, is a risky activity, but everyone who drives a car is not for that reason necessarily negligent, because a certain type and amount of driving is not only acceptable but necessary. It is only when a driver drives too fast or while intoxicated that his or her particular mode of driving behavior becomes negligent. (See generally *United States v. Carroll Towing Co.*, 159 F.2d 169 (2d Cir. 1947).)

Translating these basic notions over to the explosives industry, obviously the activities of manufacturing, supplying, and using explosives are risky activities. But they become negligent activities only if those engaging in them do not take sufficient precautions to reduce (but not necessarily to eliminate) the risks. Thus, the plaintiff who seeks to hold the dynamite manufacturer liable in negligence for harm caused by an allegedly defective stick of dynamite will not be allowed to reach the jury unless he proves that the manufacturer failed to take reasonable steps to avoid product defects and that as a consequence of such failure the defendant produced a defective stick of dynamite which ultimately and proximately caused the plaintiff's injuries. (See e.g. Sosa v. *Atlas Powder Co.* 236 F.2d 388 (5th Cir 1956).) If the plaintiff succeeds in proving these elements, then in the absence of any legal defenses (which are considered in the next section) he will be entitled to recover from the defendant manufacturer. (See e.g. Morris v. E.I. du Pont de *Nemours & Co.* 109 S.W.2d 1222 (Mo. 1937).)

Given the difficulties and complexities of proof in the plaintiff's attempting to demonstrate the unreasonableness of the defendant manufacturer's production methods, it is not surprising that some courts have permitted an inference of negligent manufacture to be drawn from the fact that the defendant produced and distributed a defective explosive. (See e.g. *Dement v. Olin-Mathieson Chemical Corp.* 282 F.2d 76 (5th Cir. 1960), applying the doctrine of *res ipsa loquitur.*) However, some courts have refused to recognize this special rule. (See e.g. Mattevich v. *Hercules Powder Co.* 3 Utah 2d 283, 282 P.2d 1044 (1955), refusing to apply *res ipsa loquitur* doctrine.) Presumably, in States recognizing this special rule would also be available to plaintiffs in actions brought against explosives handlers. (See e.g. *Tassin v. Louisiana Power & Light Co.* 250 La. 1016, 201 So.2d 279 (1967).)

These same negligence principles apply to other activities engaged in by explosives manufacturers, including marketing their products. Thus a dynamite manufacturer will be liable in negligence for unreasonably failing to warn of hidden dangers associated with use of its products. (See e.g., Eck v. E. I. *du Pont de Nemours & Co.* 393 F.2d 197 (7th Cir 1968).) And these principles apply to all other non-manufacturer suppliers of explosives with respect to their own commercial activities. Thus, a retailer who sells explosives to persons obviously incompetent to handle such risky products is negligent toward those eventually injured by an accidental explosion. (See e.g., *Pitt Explosives Co. v. Edwards* 86 Ga. App. 376, 68 S.E.2d 366 (1951).) And explosives handlers are liable for harm caused by their negligent conduct. (See e.g., *Tassin v. Louisiana Power & Light Co.* supra. See also separate section *infra* on explosives users.)

Warranty

Warranties are legal obligations incurred by commercial sellers as an incident to the sale of goods, or products. They are by and large creatures of statute—in most States today versions of the Uniform Commercial Code article 2. Three basic types of warranties are relevant here: 1) express warranties, in which the seller actually promises that the product will perform in a prescribed manner (see Uniform Commercial Code § 2-313); 2) implied warranties of merchantability, in which the seller promises nothing but is held by the law "impliedly" to have warranted that his products are free from defects (see Uniform Commercial Code § 2-314); and 3) implied warranties of fitness for particular purpose, in which the seller knows of special requirements of the buyer and of the buyer's reliance and supplies a product that fails to meet those requirements (see Uniform Commercial Code § 2-315). All three types of warranties have been held to accompany the sale of explosives. (See, e.g. *Hercules Powder Co. v. Rich* 3 F.2d 12 (8th Cir 1924) *cert. denied* 268 U.S. 692 (1924) (express warranty that fuse would burn at rate of 1 ft per minute); *Arbiino v. E. I. du Pont de Nemours & Co.* 281 F.2d 434 (2nd Cir. 1958) (implied warranty that fuse and dynamite were nondefective); and *United States Casualty Co. v. Hercules Powder Co.* 4 N.J. Super 444, 67 A.2d 866 rev'd on other grounds 4 N.J. 157, 72 A.2d 190 (1950) (fuse unfit for purchaser's particular purposes).)

Comparing these warranty theories with the negligence theory considered earlier, two important differences should be observed. On the *one* hand, it is not necessary for the plaintiff in a warranty case to prove, as the plaintiff must prove under negligence, that the defendant explosives seller acted unreasonably. It is sufficient that the product failed for whatever reason to meet the standards imposed by law at the time of sale: promised performance (express warranty), freedom from defects (implied warranty of merchantability), and suitability to purchaser's special needs (implied warranty of fitness for particular purpose). On the other hand, however, the plaintiff must prove other elements not required in a negligence case. In some jurisdictions, for example, the plaintiff must prove privity of contract—i.e., that he purchased the explosives directly from the defendant. (See, e.g. *Green v. Equitable Powder Mfg. Co.* 95 F. Supp. 127 (W.D. Ark. 1951) (negligence action allowed against explosives manufacturer warranty action barred because of lack of privity). Many courts today do not require privity to be established in products liability actions based upon warranty theories. (See, e.g., *Henningsen v. Bloomfield Motors, Inc.*, 32 N.J. 358, 161 A.2d 69 (1960).)

Misrepresentation

Misrepresentation is a tort theory of recovery that overlaps somewhat with express warranty. A main difference between them is that the tort doctrine is not dependent upon the existence of contractual privity between the plaintiff and defendant. As set forth in Restatement of Torts, Second § 402 B, the essence of the tort is a misrepresentation (whether or not negligently made) to the public by a commercial seller of a product that harms someone who justifiably relies thereon. Commercial sellers of explosives who misrepresent their products are liable for harm proximately resulting. (See, e.g., *Marsh v. Usk Hardware Co.*, 73 Wash. 543, 132 Pac. 241 (1913).)

Strict Liability in Tort

Strict liability in tort is liability for harm caused by defective products and ultrahazardous conduct irrespective of fault on the actor's or seller's part and irrespective of the requirements, such as privity of contract, that sometimes accompany warranty theories. Members of the explosives industry are exposed to two major forms of strict liability in tort: 1) strict liability imposed primarily on commercial transporters and users of explosives based upon the fact that these activities are considered abnormally dangerous (see Restatement of Torts, Second, §§519 and 520); and 2) strict liability imposed on the sellers of explosives based upon the fact of their having sold defective products (see Restatement of Torts, Second, § 402 A). Consideration of the first of these types of strict liability will be deferred to a later section dealing specifically with the liabilities of commercial transporters and users. The focus in this section will be on the strict liability of commercial sellers of defective explosives.

According to section 402A of the Restatement of Torts, Second, in order to recover in strict liability an injured plaintiff must establish that the product was in a defective condition unreasonably dangerous at the time it left the defendant seller's control and that such defective condition proximately caused the plaintiff's injuries. The rule applies to all commercial sellers in the chain of distribution, including retailers and wholesalers. The essential element of proof is that the product was defective at the time of sale by defendant. Full consideration of the different ways a product can be said to be "defective" will be deferred to later sections dealing with recurring fact patterns in cases involving allegedly defective explosives. The important point here is to understand that the focus in a strict liability case is on the product, rather than on the defendant's conduct. Even if an explosives manufacturer exercises due care to avoid flaws in its explosives, it will be held liable if flaws arise and cause harm. (See Restatement of Torts, Second, § 402 A(2)(a).) A clear majority of American jurisdictions recognize strict liability for sellers of defective products. (See CCH Prod. Liab. Rep. ¶ 4060), and a number of courts have applied that doctrine in cases involving allegedly defective explosives. (See, e.g., *Hall v. E. I. du Pont de Nemours & Co., Inc.*, 345 F. Supp. 353 (E.D.N.Y. 1972); *Clay v. [illegible] Co.*, 317 F. Supp. 288 (D.C. Colo. 1969); *Canifax v. Hercules Powder Co.*, 237 Cal. App.2d 44, 46 Cal. Rptr. 552 (1965); *Cooley v. Quick Supply Co.*, 221 N.W.2d 763 (Iowa 1974).)

The Major Defenses

The major defenses available to members of the explosives industry in products liability actions fall into three basic categories: 1) disclaimers, 2) contributory fault, and 3) intervening cause. The third is not technically a defense inasmuch as the plaintiff must prove that his injuries were proximately caused by the defendant's conduct. As a practical matter, however, the defendant raises the issue of intervening cause, arguing that the negligent conduct of explosives users constitutes a break in the chain of proximate causation. Thus intervening cause may be treated as a defense for present purposes.

Disclaimers

A disclaimer is a term in a contract purporting to exempt the disclaiming party from liability for future events in which liability would otherwise ordinarily attach. Although no authority has been found addressing the question of the effectiveness of disclaimers in cases involving defective explosives, it is very likely that the rules which apply generally in products liability apply here as well. As a general rule in products liability cases in which the plaintiffs are individuals physically injured by allegedly defective products, disclaimers are held invalid by courts as being against public policy, whether the plaintiff seeks to recover on the basis of negligence (see, e.g., Uniform Commercial Code § 1-102(3); R. Hursh & H. Bailey, American Law of Products Liability § 2:7 (2d ed. 1974)); express warranty (see, e.g., Uniform Commercial Code § 2-316(1)); implied warranty (see, e.g., *Henningsen v. Bloomfield Motors, Inc.,* 32 N.J. 358, 161 A.2d 69 (1960)); misrepresentation (see *Clements Auto Co. v. Service Bureau Corp.,* 444 F.2d 169 (8th Cir. 1971)); or strict liability (see, e.g., Restatement of Torts, Second §402 A, comment m; *Vandermark v. Ford Motor Co.,* 61 Cal.2d 256, 37 Cal. Rptr. 896, 391 P.2d 168 (1964)). On the reasonable assumption that these same rules apply in cases involving allegedly defective explosives, plaintiffs physically injured in accidental explosions should not be barred simply because of the inclusion of disclaimer language in the contracts of sale and distribution.

On the other hand, there is more reason to expect that disclaimers will be given effect as between business entities in cases where the harm suffered is economic rather than physical. Two business entities, dealing at arms' length from roughly equal bargaining positions, arguably should be allowed to allocate responsibilities between them by contract. Some courts have given effect to disclaimers in indemnity and contribution actions between business entities. (See, e.g., *Williams v. Chrysler Corp.,* 148 W.Va. 655, 137 S.E.2d 225 (1964); but see *Ford Motor Co. v. Tritt,* 244 Ark. 883, 430 S.W.2d 778 (1968).) Thus, were a large explosives distributor to seek indemnity from the manufacturer after being held liable in a products liability action brought by an injured victim of an accidental explosion, the court might give effect to a disclaimer in the contract of sale between the explosives manufacturer and the distributor.

Contributory Fault

Certainly when the basis of the plaintiff's action against the explosives seller is negligence, contributory fault on the part of the plaintiff will reduce (or eliminate, if comparative fault is not applicable) the plaintiff's recovery. (See, e.g., *Dalby v. Hercules, Inc.,* 458 S.W.2d 270 (Mo. 1970).) When the plaintiff seeks recovery on the basis of warranty, courts today are likely to speak in terms of the plaintiff's conduct breaking the chain of proximate causation, especially when the plaintiff is shown to have been aware of the defective condition of the defendant's product. (See, e.g., Uniform Commercial Code 2-316 (3)(b) comment 8, & 2-715 comment 5.) The majority rule in products liability cases involving strict liability in tort is that only the form of contributory fault commonly referred to as "assumption of the risk"—in which the plaintiff knows or has reason to know of the defective condition of the product—will reduce or bar the plaintiff's recovery. (See, e.g., Restatement of Torts, Second §402 A, comment n; but see *Codling v. Paglia,* 32 N.Y.2d 330, 298 N.E.2d 622, 345 N.Y.S.2d 461 (1973).) This general rule reflects a policy favoring liability of commercial sellers of defective products in all cases except those involving fairly gross behavior on the part of plaintiffs.

Examining recent products liability cases involving allegedly defective explosives sold to commercial users, it appears that courts have been sympathetic to defendants' arguments that the users of their products, rather than the products themselves, are to be blamed for the accidents. These judicial sympathies manifest themselves in several ways. Courts have been willing to weigh user misconduct fairly heavily as an independent bar to recovery. (See, e.g., *Hercules Powder Co. v. Hicks,* 453 S.W.2d 583 (Ky. 1970).) And they have been willing to give such misconduct weight in deciding that the plaintiff's circumstantial proof of product defect was insufficient. (See, e.g., *Hopkins v. E. I. du Pont de Nemours & Co.,* 212 F.2d 623 (3rd Cir. 1954), *cert. den.* 348 U.S. 872 (1954).) The main reason for this willingness to weigh user misconduct more heavily in explosives cases than in cases involving other types of products appears to be the fact that explosives are not, as a general rule, "consumer products" in the same sense as household appliances. (*But see* p. 217, *infra.*) Commercial users of explosives are generally assumed to be expert and can be relied upon to reduce the incidence of accidental explosions. Of course, when explosive products are sold to relatively incompetent users such as young children, contributory fault plays much less of an important role in reducing or barring the seller's liability. (See, e.g., *Wendt v. Balletto,* 26 Conn. Super. 367, 224 A.2d 561 (1966).)

Intervening Cause

The main difference between this "defense" (see earlier comment) and the defense of contributory fault (just considered) is the fact that in cases involving intervening cause, the plaintiffs are not the same persons who misused or mishandled the explosives. Although the victims in these cases are innocent of personal wrongdoing, they will be denied recovery against the sellers of allegedly defective explosives if the conduct of those using the explosives was so negligent as to constitute an intervening or superseding cause of the plaintiffs' injuries. (See, e.g., *Hercules Powder Co. v. Hicks,* 453 S.W.2d

523 (Ky. 1970).) In contrast, where an innocent third party brought a strict liability action against those in charge of storing explosives, the Supreme Court of Alaska rejected the defendant's intervening cause argument as a matter of law even in the face of proof that vandals had broken into the storage area and deliberately set off the explosion. (See *Yukon Equipment, Inc. v. Fireman's Fund Ins. Co.*, 585 P.2d 1206 (Alaska 1978).)

Actions Against Manufacturers and Other Commercial Sellers of Explosives

The objective in this and the following sections will be to examine the significant fact patterns that tend to occur in this area. The focus will not be on legal doctrine, but on the basic fact patterns and the reactions of courts to them.

Product Flaws

As developed earlier, an injured plaintiff stands a good chance of recovering against the manufacturer and other commercial sellers of explosives if he can prove the existence of a product defect in existence at the time of sale by the defendant. A flaw is a type of defect which consists of the inadvertent failure of a product unit, or batch of units, to conform to the intended product design. Flaws are what laypersons most often think of as "defects." The flaws most frequently encountered in explosives cases are "bad batches" — for example, sticks of dynamite, some of which contain too much and some too little explosive ingredients due to improper mixing during manufacture.

The greatest source of difficulty confronting plaintiffs in flaw cases is not so much conceptual as practical. Because explosives always "self-destruct" in use, it is usually difficult for plaintiffs to obtain direct evidence of product flaws. When other types of products break unexpectedly, experts can sometimes reconstruct the products and determine the existence of flaws. But with explosives, such reconstruction is almost never possible. Consequently, plaintiffs in cases in which accidental explosions are caused by alleged flawed explosives are almost always forced to rely upon circumstantial, rather than direct, evidence of the existence of product flaws.

A classic example of how a plaintiff can successfully build a case based on circumstantial proof is presented in *Morris v. E. I. du Pont de Nemours & Co.*, 109 S.W.2d 1222 (Mo. 1937). The plaintiff in that case claimed that the defendant explosives manufacturer, through its employees, had negligently mixed a batch of dynamite so as to cause the stick used by the plaintiff to explode prematurely. The plaintiff's proof, which the court held to be sufficient to reach the jury, consisted of the following: 1) purchase of the dynamite from the defendant by the plaintiff's employer; 2) careful handling and storage of the dynamite up to the time it came into the plaintiff's hands on the day of the accident; 3) careful handling of the dynamite by the plaintiff up to the time of the premature explosion; 4) difficulties experienced by other employees with dynamite from the same batch; and 5) expert testimony to the effect that the dynamite that injured the plaintiff was unevenly mixed. Of course, because the plaintiff proceeded on a negligence theory, the record also included testimony on both sides relating to the issue of due care in manufacture. Today, under a strict liability in tort theory, that last described evidence would not be necessary. But the plaintiff must still prove the existence of a defect, even under strict liability theories. And on the issue of circumstantial proof of defect, the Morris case is still good law.

Where the plaintiff is unable to build a solid circumstantial case, courts are apt to rule in favor of the defendant manufacturer as a matter of law. Especially where there is evidence of mishandling of the explosives at the time of the accident, the plaintiff may meet with judicial disapproval regarding the sufficiency of his proof of defect. (See, e.g., *Gose v. Atlas Powder Co.*, 235 F.2d 369 (5th Cir. 1956); *Hopkins v. E. I. du Pont de Nemours & Co.*, 212 F.2d 623 (3rd Cir. 1954), *cert. den.* 348 U.S. 872 (1954).) Another source of difficulty often encountered by plaintiffs in these flaw cases is the necessity of accounting for the conditions of storage and handling between the time of sale by the defendant and use by the plaintiff. That this may even defeat claims based upon strict liability in tort is suggested by *Clay v. Ensign-Bickford Co.*, 307 F. Supp. 288 (D. C. Colo. 1969), in which the trial court conceded that the fuse was defective at the time of the explosion but held that the plaintiff failed to prove that the defect originated with the defendant manufacturer.

Product Designs

Although products liability actions based on allegedly defective designs are escalating in frequency in many other product areas, they are relatively rare in actions against explosives manufacturers. Ordinarily, explosives are supposed to explode. When they explode prematurely, the tendency ry is to explore the possibility of a product flaw or misloading. The only type of case that could be said to involve the defective design of an explosive would be one in which the explosive was deliberately made too strong or too weak. But even there the tendency would be to treat such a case as involving the failure of the defendant adequately to warn users of the explosive characteristics of its products.

Marketing

The cases involving claims by injured plaintiffs based on the manner in which explosives are marketed may be grouped into three basic categories: 1) cases in which the defendant's product fails to perform as promised by the defendant; 2) cases in which the defendant fails to warn users of hidden risks associated with its product; and 3) cases in which the defendant sells or distributes the explosives to persons who are obviously incompetent to handle them. Cases in the first of these categories may involve express warranties. (See earlier discussion pp. 203-204 *supra*.) They may also involve negligence, as in *Rasinkas v. Olin-Mathieson Chemical Corp.*, 8 Mich. App. 638, 155 N.W.2d 286 (1967), where the seller of dynamite advised the plaintiff to use too much explosive in the primer.

By far the most significant category of marketing cases involves alleged failures to warn explosives users of risks that are not obvious. Although often based upon allegedly negligent omissions by defendants (see Restatement of Torts, Second, § 388), failure to warn is also generally recognized as a basis for imposing strict liability. (See *generally* Restatement of Torts Second, 402 A, comments h and j.) As a general rule, manufacturers and other commercial product sellers owe a duty to warn of risks that are not likely to be obvious to persons who will foreseeably use their products, and that, with such warnings, the users are in a position to avoid. Because users of explosives are presumably knowledgeable regarding many of the risks associated with these products, the manufacturer's duty to warn tends to be drawn somewhat more narrowly than in other product areas. (See, e.g., *Croteau v. Borden Co.*, 277 F. Supp. 945 (E. D. Pa. 1968), aff'd 395 F.2d 771 (3rd Cir. 1968); *Hercules Powder Co. v. Hicks*, 453 S.W. 2d 589 (Ky. 1970).)

One aspect of controversy concerning the explosives manufacturer's duty to warn is the question of the proper addressees of the warnings. Some courts have held that it is sufficient if the supervisory personnel in charge of directing blasting operations receive warnings, negating any requirement that the manufacturer attempt to warn those actually using the explosives. (See, e.g., *Bryant v. Hercules, Inc.*, 325 F. Supp. 241 (W. D. Ky. 1970).) Other courts have held that the manufacturer of explosive products must attempt to warn those actually using these products of risks that may be hidden to them notwithstanding the fact that information is supplied to the manufacturer's immediate vendee. (See, e.g., *Fisk v. E. I. du Pont de Nemours & Co.*, 393 F.2d 197 (7th Cir. 1968); *Shell Oil Co. v. Gutierrez*, 119 Ariz. 426, 581 P. 2d 271 (1978).) In other product areas, with the exception of prescription drugs, courts generally require warnings to be gotten to the actual users. (See, e.g., *Hubbard-Hall Chemical Co. v. Silverman*, 340 F.2d 402 (1st Cir. 1965) (insecticide poison); *McLaughlin v. Mine Safety Appliances Co.*, 11 N.Y.2d 62, 226 N. Y.S.2d 407, 181 N.E.2d 430 (1962) (heat blocks for use in rescue operations).)

Regarding the third category of cases focusing on the explosives seller's manner of marketing its products—cases in which explosives are sold to persons obviously incompetent to handle them—retailers are occasionally exposed to liability on that basis. (See, e.g., *Wendt v. Balletto*, 26 Conn. Supp. 367, 224 A.2d 561 (1966) (sale to minor); *Flat Explosives Co. v. Edwards*, 84 Ga. App. 370, 66 S.E.2d 386 (1951) (sale by unlicensed retailer to inexperienced users).) However, courts have been reluctant to hold explosives manufacturers responsible for failing to follow up on the ultimate distribution and manner of use of their products. (See, e.g., *Dosa v. Apache Powder Co.*, 430 F.2d 1317 (5th Cir. 1970); *Flat Explosives Co. v. Edwards*, 85 Ga. App. 404, 71 S.E.2d 747 (1952).)

Actions Against Manufacturers and Other Commercial Sellers of Explosives Components

"Component" is a term of art in products liability law. In the present context it is synonymous with "ingredients." Commercial sellers of explosives components are entities that manufacture and sell the chemical ingredients of explosives. Most often the ingredients are sold to explosives manufacturers.

Product Flaws

No cases have been found in which an action has been brought against a commercial seller of explosives components on the grounds that the component was flawed at the time of sale. This paucity of reported decisions undoubtedly reflects the earlier described elsewhere that most product failures in connection with explosives occur as a result of the improper mixing of ingredients by the explosives manufacturer. (See p. 206, supra.) And those few instances of flawed explosives that might be theoretically traceable to flawed components would pose insurmountable problems of proof as a practical matter. However, as a matter of legal theory there is little doubt that the seller of a product component proven to have been flawed at the time of sale would be liable to persons injured because of such product flaw. (See, e.g., Clark v. Bendix Corp., 345 N.Y.S.2d 662, 42 A.D.2d 727 (1973); *Rainbolt v. Rexmen Equipment Co.*, 441 P.2d 993 (Okla. 1968).) Whether courts would give effect to a disclaimer in the contract of sale of the component as between the component seller and the explosives manufacturer is not clear. (See pp. 204-205, *supra*.)

Product Designs

Here, too, it is unlikely that a plaintiff injured in an accidental explosion would bring an action against the seller of a component based on a theory of defective design. Typically, the explosives manufacturer decides what it needs in the way of ingredients, and orders them specifically by description. The components supplied to explosives manufacturers are basic chemical compounds. It is difficult to envision a design-based theory of recovery against the component seller in the typical case.

In other product areas, suppliers of product components have been held liable for the designs of the finished product even where the component was not dangerous by itself. A recent decision by the Supreme Court of Mississippi (*Dawson v. S.A. Allen Inc.*, 355 So. 2d 77 (Miss. 1978)) held that the supplier of a component could be held liable when such component is intended to be used only in conjunction with a second component and when so combined the combination of the two is unreasonably dangerous. The finished product in that case was a pulpwood cutter, and the component was a lifting shear attachment. Even though the dangers posed by the combination could be eliminated only by a modification in design of the larger machine, the seller of the component was held liable based on its knowledge of the dangers and its involvement in manufacturing a component designed specifically for use in the finished product.

In contrast, the manufacturer-seller of bulk sulfuric acid was held not to owe a duty to the general public to make sure that commercial purchasers of its product did not combine the acid with other ingredients to produce unreasonably dangerous chemical combinations. (See Walker v. *Stauffer Chemical Corp.*, 19 Cal.App. 3d 669, 96 Cal. Rptr. 803 (1971).) The plaintiff in that case was injured when a drain cleaning product containing the defendant's sulfuric acid exploded during use. On balance, the bulk sulfuric acid manufacturer seems closer in the model of explosives components than does the manufacturer of the machinery component. Assuming that the explosives manufacturer is knowledgeable regarding what it wants in the way of components and assuming that the component manufacturer delivers exactly what is ordered, it is unlikely that liability would extend to the seller of basic chemical constituents of explosives. When the seller of basic components has reason to know that the buyer is relying on the seller's judgment in recommending what type of component to use, liability may extend to the component seller. (See, e.g., Krammer v. Edward Hines *Construction Co.*, 16 Ill. App. 3d 793, 306 N.E. 2d 606 (1974) (seller supplied wrong grade of lumber for scaffolding).) But assuming the absence of such reliance in most sales of basic components to explosives manufacturers, liability probably would not extend to the component sellers.

Marketing

Given the presumed expertise of explosives manufacturers, it is difficult to see how sellers of explosives components in the typical instance could be held to a duty to warn of the risks associated with their products. Even when the purchaser of explosives components is an individual, liability on the basis of failure to warn will be denied if the user is an explosives expert. (See, e.g., Croteau v. Borden Co., 277 F. Supp. 945 (D. C.E. D. Pa. 1968) Aff'd 395 F.2d 771 (3rd Cir. 1968) (plaintiff was a lab technician conducting an experiment on a solid rocket fuel component).) However, when the manufacturer of a component knows or has reason to know of the purchaser's ignorance of the risks or knows that the purchaser is assembling the component into a dangerous combination without adequate warnings to users ignorant of the risks, liability may be imposed on the component seller for failing to warn. (See, e.g., *E.I. du Pont de Nemours & Co. v. McCain*, 414 F.2d 369 (5th Cir. 1969) (liability imposed even where component sale by defendant was inert-defendant's name was on the label of the finished product).)

On balance, it is unlikely that sellers of explosives components would be liable for failure to warn in the normal situation in which the components are sold to explosives manufacturers. This conclusion is somewhat strengthened by the earlier described reluctance of courts to impose duties upon explosives manufacturers to follow up sales of their products with efforts to reduce carelessness in their handling and use. (See p. 207, *supra*.)

Actions Against Manufacturers and Other Commercial Sellers of Explosives Accessories

Accessories refers to products normally used in connection with explosives, including blasting caps and fuses.

Product Flaws

In contrast to the situation with regard to explosive components, a number of cases have been reported in which injured plaintiffs have sought to recover from manufacturers and other sellers of explosive accessories on the basis of product flaws. (See, e.g., *Haffenstier v. Hercules Powder Co.*, 315 F.2d 282 (8th Cir. 1963) (blasting caps); *Comeril v. Olin Mathieson Chemical Corp.*, 282 F.2d 74 (8th Cir. 1960) (blasting caps); *United States Casualty Co. v. Hercules Powder Co.*, 4 N.J. Super. 444, 67 A.2d 880 (1949), rev'd on other grounds 4 N.J. 157, 72 A.2d 180 (1950) (fuse).) To some extent then other product manufacturers and sellers (commercial suppliers) of explosives accessories are exposed to liability (in many jurisdictions, strict liability) for harm caused by flawed products. As is the case of explosives manufacturers, the difficulties encountered by injured plaintiffs are in proving that a defect was present at the time of sale. (See p. 206, *supra*.) Indeed, the difficulties are likely to be comparatively greater in cases involving blasting caps due to their smaller size and relatively greater mobility and the correspondingly greater likelihood that injured plaintiffs will be unable to prove that the product was handled carefully between the time of original purchase and the time of the accident. (See, e.g., *E.I. du Pont de Nemours & Co. v. Dabbrae*, 236 Fed. 690 (5th Cir. 1916); *Hicks v. E. I. du Pont de Nemours & Co.*, 246 F. Supp. 580 (D.C. Okla. 1965).)

Interestingly enough, plaintiffs who have brought similar actions against fuse manufacturers appear to have fared somewhat better in reaching the jury with circumstantial proof of product defects. (See, e.g., *Hercules Powder Co. v. Rich*, 3 F.2d 12 (8th Cir. 1924); *United States Casualty Co. v. Hercules Powder Co.*, 4 N.J. Super. 444, 67 A.2d 880 (1949), rev'd on other grounds 4 N.J. 157, 72 A.2d 180 (1950); *Bolven City v. Ensign-Bickford Co.*, 307 F. Supp. 266 (D.C. Colo. 1969) (plaintiffs proved defect at time of accident but not at time of sale).) One practical difference between blasting caps and fuses that may help to explain this difference in treatment is the fact that fuse ordinarily is sold in reels, from which the users take whatever lengths are required under the varying circumstances of use. Thus, more often than in the case of blasting caps, the unused portion of the fuse may be examined for defects after the accident and if defects are discovered the plaintiff can argue that the fuse that caused the accident had the same defects. Another reason plaintiffs may fare better in fuse cases is the fact that eyewitnesses are able to testify regarding the behavior of the fuse at the time of the accident in ways that directly point to the existence of a defect. (See, e.g., *Hercules Powder Co. v. Rich*, *supra* (fuse burned too quickly); *Cooley v. Quick Supply Co.*, 221 N.W.2d 763 (Iowa 1974) (user could not tell if fuse was burning).)

Product Designs

Design cases would appear more likely to arise here than in the case of explosives and components given the somewhat more mechanical nature of some accessories. For example, one can envision an action being brought on the ground that a particular type of blasting cap was designed so as to allow accidental detonation too easily. However, no reported cases have been found in which the plaintiff proceeded against the manufacturer or other commercial seller of an explosives accessory on the basis of an allegedly defective design.

Marketing

Injured plaintiffs have brought actions against accessory manufacturers and sellers on the ground that adequate warnings did not accompany the products into the hands of the ultimate users. With respect to fuses, plaintiffs typically argue that they were not adequately warned of the burning characteristics of the products. Especially where the fuse is sold as "safety fuse," such arguments have been successful. (See, e.g., *Canifax v. Hercules Powder Co.*, 237 Cal. App.2d 44, 46 Cal. Rptr. 552 (1965); *Cooley v. Quick Supply Co.*, 221 N.W.2d 763 (Iowa 1974).) The plaintiffs in the blasting cap cases have more frequently been persons outside the class of professional users originally intended by the manufacturer to use the products, who have argued that the defendant failed adequately to warn against the possibility of the caps exploding accidentally

Reflecting the tendency of courts to refuse to extend the responsibilities owed by explosives manufacturers (see p. 205, *supra*) and component manufacturers (see p. 205, *supra*) to extralegal incompetent persons into whose hands these dangerous products sometimes come, some courts have refused to hold blasting cap manufacturers for failing to label their products as explosives. (See, e.g., *Bell v. E. I. du Pont de Nemours & Co.*, 514 F.2d 715 (8th Cir. 1975); *Littlehale v. E. I. du Pont de Nemours & Co.*, 380 F.2d 274 (2d Cir. 1967).) However, at least one court has not only recognized the duty of blasting cap manufacturers to warn children of the explosive nature of their products but has suggested that injured plaintiffs may join in a single tort action against all major members of the blasting cap industry together with their trade association. (See *Hall v. E. I. du Pont de Nemours & Co., Inc.*, 345 F. Supp. 353 (E.D.N.Y. 1972).)

Actions Against Commercial Transporters and Users of Explosives

Commercial transporters and users of explosives are subject to strict liability for harm to persons and property caused by their activities to an extent that in some ways can be said to exceed the strict liability of sellers of defective products. Although this rule is not strictly speaking a rule of products liability, it deserves brief mention in this analysis. The general rule is set forth in sections 519 and 520 of the Restatement of Torts Second. In essence, persons engaged in activities considered to be abnormally dangerous are strictly liable without regard to the degree of care exercised. The rule applies whether or not the abnormally dangerous activity is commercial, but a clear majority of its applications involve commercial activities. A number of courts in recent years have imposed strict liability in tort for harm to the persons and property of others caused by transporters and users of explosives. (See, e.g., *Ward v. H. B. Zachry Const. Co.*, 570 F.2d 992 (10th Cir. 1978); *Yukon Equipment, Inc. v. Fireman's Fund Ins. Co.*, 585 P.2d 1206 (Alaska 1978) (storers of explosives strictly liable even when explosion caused by vandals); *Ianuzzo v. Cayuga Const. Corp.*, 411 N.Y.S.2d 699, 65 A.D.2d 745 (1978) (blasters strictly liable); *Cf. O'Connor v. E.J. DiCecco & Sons, Inc.*, 378 N.E.2d 889 (Mass. 1977) (consequential damage from blasting is actionable only on proof of negligence).)

HOW WOULD THESE EXPOSURES TO LIABILITY CHANGE IF CONGRESS REQUIRED THE INCLUSION OF TAGGANTS IN EXPLOSIVES?

Factual Assumptions

A number of factual assumptions will be carried through the following analysis of the potential changes in the products liability exposure of the explosives industry. At the end of the analysis, each assumption will be hypothetically altered to permit consideration of alternative outcomes. These assumptions are included here to render manageable what follows. They are not meant to reflect any judgment by the author regarding the merits of the issues to which they relate.

Congress will require the inclusion of both identification and detection taggants. Identification taggants are small pieces of coded material capable of surviving an explosion in sufficient numbers to be retrieved afterward. They are mixed with the other ingredients of explosives at the time of manufacture. When retrieved following an explosion they allow the manufacturing source and date of manufacture of the explosive to be determined. Detection taggants are small pieces of material that emit traces of a gas capable of being detected by sensors. Explosives containing detection taggants presumably could be discovered prior to detonation by the use of gas-sensitive monitoring devices. Although the author understands that detection taggants are still in the relatively early stages of development, the present analysis will assume their required inclusion in the interest of completeness.

The features of the taggants required to be included will be specifically described by regulation. Two basic regulatory approaches are available by which to describe the taggants which would be required to be included in explosives: 1) design standards, in which the design specifications of the taggants are described with relative specificity; and 2) performance standards, in which the taggants are described in terms of expected performance — e.g., their capability of being retrieved after an explosion or detected before one. With respect to most consumer products performance standards are preferred over design standards because they leave the producers relatively free to provide consumers with choices among designs. In the present context, however, it may be assumed safely that uniformity in the design of taggants is more desirable than variation and therefore that design standards will be adopted by regulation after adequate testing.

Congress will exclude black and smokeless powders from the list of explosives required to contain taggants. The following analysis will focus on solid explosives, such as dynamite. Because the inclusion of taggants in explosive powders would present somewhat different products liability issues, that possibility will be deferred until later.

Government-supervised testing indicates explosives containing taggants are "safe" for normal handling. The assumption here is that Congress will not require the inclusion of taggants in explosives before testing reveals no accompanying safety hazards. However, the word "safe" must be put in quotation marks because of the inherent limits of any testing program — all possible conditions of use cannot be anticipated and tested against. Thus, notwithstanding this assumption, experts are likely to be available to plaintiffs who will testify in good conscience that on the facts of a particular case the taggants played a role in causing an explosion involved in a particular case.

Taggant manufacturers will sell the taggants directly to explosives manufacturers. The author is aware of a proposal to have the Federal Government purchase taggants and then sell them to explosives manufacturers. That alternative will be addressed in a subsequent section.

Congress will provide no special immunities or other legislative adjustment of liabilities. Again the author is aware of suggestions that Congress adjust the exposures to liability of members of the explosives industry and will return to consider those possibilities in a later section.

Changes in Explosives Manufacturers and Sellers Exposures to Liability

In the following analysis, the question of whether these manufacturers and sellers of explosives can successfully raise as a defense the fact that they are required by law to include taggants in their products will be deferred until the underlying questions of whether injured plaintiffs could succeed in proving defects have been addressed.

Claims That the Taggants Caused Accidental Explosions—Proof of Defect

At the outset, it must be recognized that in cases in which injured plaintiffs claim that taggants caused accidental explosions, technically they will be asserting alleged defects in design rather than in production. It will be recalled from an earlier discussion that a flaw consists of an inadvertent failure of a product unit to conform to the intended product design. (See p. 208, supra.) Because taggants are to be included in explosives intentionally, technically they are not flaws, but part of the product designs. Will or should this circumstance make a difference in the way courts react to the plaintiffs' proof and arguments in cases involving accidental explosions? Functionally, taggants that are proven to cause accidental explosions are quite flaw-like. (The question of whether plaintiffs will actually succeed in proving that the taggants caused the explosions will be addressed shortly.) That is, from the point of view of the injured user of the explosives, the taggants would act very much like flaws — i.e., they would constitute bits of "foreign" material that would not enhance, but rather would detract from, the intended performance of the explosives. Presumably, any instability produced by their inclusion would be a feature against which ordinarily careful handling would constitute inadequate protection. On the assumption that their inclusion causes accidents, they would be the functional equivalent of "designed-in flaws."

The interesting question is whether, putting to one side the functional equivalency of these taggants to product flaws, defendant manufacturers would be permitted to argue as a matter of public policy that the benefits to society at large sufficiently outweigh the risks presented to explosives users as a justification for the inclusion of taggants. (Again, the narrower question of whether it should matter that the Government forces this decision on explosives manufacturers will be deferred until later.) What makes this question particularly intriguing is the fact that influential legal commentators have recognized that a "cost-benefit" analysis is appropriate in determining whether product designs are unreasonably dangerous. (See, e.g., Wade, On the Nature of Strict Tort Liability for Products, 44 Miss. L.J. 825 (1973).)

On balance, the circumstances surrounding the inclusion of taggants in explosives appears to be sufficiently different from most cases involving allegedly defective product designs to cause this writer to doubt that courts would give much weight to such policy arguments on behalf of defendants. In most product design cases, the risks and benefits to be balanced off against each other accrue to the same more or less limited group of persons, typically the product users. With respect to taggants, the group put to risk—the users—are a much smaller group than the group benefited—society at large. In product design cases in which one distinct group is benefited and another put at risk, courts have tended to impose liability on product designers, in part on grounds of basic fairness. (See, e.g., *Passwaters v. General Motors Corp.*, 454 F.2d 1270 (8th Cir. 1972).) Admittedly, in most cases of this sort the nonusers are the ones who are put to risk and the users the ones who benefit. But it would not be surprising if courts were to react similarly in these taggant cases, where the situation is the reverse.

Taking these considerations together—the functional similarity of taggants to production flaws (presumably they cause the product suddenly and without warning to self-destruct) and the general tendency for courts in products liability cases to be suspicious of allowing one group of persons to be put at risk so that a different group can benefit—it is likely that courts would treat these cases as they would treat flaw cases. That is, if the plaintiff succeeds in proving that the taggants caused an accidental explosion, the plaintiff will have proved the product to be defective and unreasonably dangerous notwithstanding efforts of manufacturers to argue "the greater good for the greater number." This conclusion draws support from the increasing reliance by courts and commentators on the test of "reasonable consumer expectations" to determine the defectiveness issue. (See *generally* Restatement of Torts, Second, § 402 A, comment i; Hubbard, "Reasonable *Human* Expectations: A Normative Model for Imposing Strict Liability for Defective Products," 29 Mercer L. Rev. 465 (1978).) Certainly from the point of view of the user of explosives, a stick of dynamite that explodes unexpectedly and without fault on the user's part could be said to fail to meet that user's "reasonable expectations." (For a consideration of the efficacy of warning users that the explosives may accidentally explode, see pp. 216-217, *infra*.)

Assuming that a plaintiff will succeed in establishing a prima facie case if he can prove that the taggants caused the accidental explosions, it remains to be considered whether it is likely that he will succeed in his proof. It will be recalled from an earlier treatment of the liability of explosives manufacturers and sellers that the major problem confronting injured plaintiffs in cases involving product defects is establishing the existence of a defect by means of circumstantial evidence. (See p. 208, *supra*.) Would the required inclusion of taggants in explosives reduce these difficulties of proof? That is, putting aside for a moment the question of whether defendants would be allowed to raise as a defense the fact that they are required by law to include taggants in their products, (see pp. 215-216, *infra*.) would plaintiffs be more likely to reach triers of fact with arguments that the explosives themselves rather than mishandling caused the accidental explosions?

Although the magnitude of the reduction in plaintiffs' problems of proof brought about by the inclusion of taggants cannot be predicted with any degree of certainty, the answer to the question is almost certainly "Yes": plaintiffs' problems of proof would be reduced. In accidental explosion cases up to now, plaintiffs almost invariably have been unable to offer direct evidence of the presence of foreign materials due to the fact that the explosives in question self-destruct in use. Once taggants are required to be included, direct proof of their presence will almost always be available—indeed, their presence based on the Federal requirement would probably be presumed.

Of course, the mere fact of the inclusion of the taggants in the explosives would not make a case for an injured plaintiff unless there were proof that the taggants caused the explosion. Would such proof be available to plaintiffs in the face of extensive Government-supervised product testing showing taggants to be "safe"? In part, the answer here depends on a factor difficult for the writer to predict at this time—i.e., the degree of unanimity among scientific professionals on the question of whether taggants may pose risks of accidental explosions. On the reasonable assumption that in this instance, as with most relatively novel technical questions relating to probable risks, some division of opinion is likely to be present among experts, then the proof needed by plaintiffs will likely be available in the form of expert testimony. In general, this expert testimony could be expected to take two basic forms: 1) testimony that the presence of even a "normal" concentration of taggants caused the accidental explosion; and 2) testimony that in a given case an "abnormal" concentration of taggants was present and caused the explosion.

Regarding the first form of expert testimony, on the assumption that some members of the scientific community believe that taggants may at least contribute to instability under certain conditions, a qualified expert will probably be available who is willing to testify in good conscience that based on the surrounding circumstances including proof of careful handling the presence of abnormal concentrations of taggants caused the accidental explosion. Without the taggants, the plaintiff's expert would be forced to rely more heavily on speculation regarding the presence of explosion-inducing foreign material, making it easier for the judge to intervene on behalf of the defendant as a matter of law. With the inclusion of the taggants the expert could more easily anchor his opinion to a specific hypothesis. Courts would continue to direct verdicts for defendants in cases where the plaintiff's other circumstantial proof was weak. But the presence of the taggants could be expected to cause this to happen somewhat less frequently. However, in a case where there is nothing or almost nothing in the way of circumstantial evidence of what caused the explosion, opinion of an expert that the explosion "may have been caused" by the taggants is unlikely to be sufficient, standing by itself, to support a conclusion of causation. (See generally 2 F. Harper & F. James, The Law of Torts 1117-1118 (1956).)

With regard to the second form of expert testimony to the effect that an abnormally high concentration of taggants caused the accidental explosion, the possibility exists that high concentration could be established by evidence other than the fact of the explosion itself. Either the expert could testify to an abnormally high number of taggants recovered at the explosion site, or the expert could testify to an abnormally high concentration of taggants in other unexploded explosives from the same lot, which should be more easily traceable given the taggant requirement. (It should be observed that proof of an abnormally high concentration would be proof of a "flaw" in the classic sense—see p. 206 supra.) If either type of independent proof of an abnormally high concentration were available, the plaintiff would very probably reach the trier of fact on a defect theory. In addition, the plaintiff should reach the trier of fact if the taggants recovered were shown to be too large or otherwise misshapen in ways that could contribute to accidental explosions. If no such independent evidence were available, as a practical matter it is difficult to see how the plaintiff's case would be strengthened simply by an assertion that a high concentration of taggants, or odd-shaped taggants, existed. With no direct evidence of the existence of these, the mere fact of explosion ought not to suffice to permit the trier of fact to conclude that the explosive was defective. Admittedly, the fact that taggants are present in the explosive in the first place adds "one more thing that can go wrong." But in the absence of independent proof of high concentration (which, perhaps significantly, the special recoverability of taggants would help make possible), as a practical matter the plaintiff's case would only be as strong as his circumstantial evidence.

In connection with the foregoing analysis of the effects of the presence of taggants on the plaintiff's proof of defect, it should be noted that the utility to the plaintiff of the first type of expert testimony—testimony that a normal concentration of taggants caused an accidental explosion — depends on the assumption made at the outset that explosives manufacturers would not succeed in raising "Government contractor" as a defense. If manufacturers were to succeed with that defense, then it would be to their advantage and not the advantage of plaintiffs to blame accidental explosions on normal concentrations of taggants.

Claims That Detection Taggants Failed to Function Properly

The basic fact pattern envisioned here is one in which the plaintiff claims to have been injured by an illegal use of explosives because detection taggants failed to operate to prevent the explosives from being used illegally. This sort of case raises a host of issues that are probably not worth pursuing in-depth at this point given the fact that detection taggants are very much more in the development stage than are identification taggants. It will be useful, however, to sketch the basic framework of analysis.

It will be recalled from an earlier discussion that normally explosives manufacturers are not liable for harm caused by abnormal uses of their products. (See p. 207 supra.) Thus, if dynamite were used by a terrorist in such a way as to harm others, the manufacturer of the dynamite would not be liable even if the dynamite could be traced to its source. However, the situation might be different in connection with detection taggants. That is, if an injured plaintiff were to prove that a detection taggant failed to function as intended, allowing the plaintiff to be harmed under circumstances where an adequate performance by the taggant would have prevented the harm, the manufacturer of the explosives in question might be exposed to liability for having sold a flawed product. In a somewhat analogous situation, courts have imposed liability for explosion damages on commercial sellers of bottled gas containing insufficient odorous contaminant to permit detection of the gas in the air by sense of smell. (See generally Annotation, Duty and Liability in Connection With Odorization of Natural Gas, 70 A.L.R.3d 1060 (1976).) To be sure the defendants in a detection taggant failure case would have an argument of intervening cause based upon the criminal conduct of the users of the explosives. (See, e.g., *Watson v. Kentucky & Ind. Bridge & Ry. Co.*, 137 Ky. 619, 126 S.W. 146 (1910); see generally pp. 205-206 supra.) However, the Supreme Court of Alaska recently imposed strict liability on a storer of explosives notwithstanding the fact that the explosion was deliberately set off by thieving vandals. (See *Yukon Equipment, Inc. v. Fireman's Fund Ins. Co.*, 585 P.2d 1206 (Alaska 1978). See also *Kreger v. General Ordnance Equipment Corp.*, 387 A.2d 384 (Pa. Super. 1978) (plaintiff watchman was criminally assaulted after mace gas failed to subdue an attacking felon).)

A major difficulty facing plaintiffs in such cases would be proving the existence of a product defect. Five hypotheses as to the cause of the breakdown in detection would include: 1) explosives aged beyond the useful life of the detection taggants; 2) explosives somehow "cleansed" of detection taggants; 3) explosives that never contained detection taggants in the first place (not included in taggant requirement, homemade, illegally imported or pre-taggants); 4) existence of explosives in containers that "defeated" taggants (might expose manufacturer to design or failure to warn liabilities); 5) breakdown in detection devices (court might hold explosives manufacturers and device manufacturers jointly liable); and 6) breakdown in personnel in charge of detection operation. Although the list appears formidable, some of these hypotheses might be eliminated by independent evidence. If such evidence were available, an injured plaintiff might reach the trier of fact in an action against the explosives manufacturer.

Significance of the Fact That Manufacturers Are Required by Law to Include Taggants

The question to be considered here is whether defendant manufacturers and sellers of explosives could argue effectively in defense of liability for accidental explosions that the taggants were required by law to be included in their products. In addressing the issue, the discussion will first center on the basic analytical principles involved apart from considerations of the extent to which a Federal taggants requirement should be given deference over the products liability law of the States. Thereafter, attention will focus upon the question of possible preemption of State law.

A possible source of guidance may be illustrated at the outset. The fact that these taggant cases are inherently design cases, discounted in importance in the earlier discussion of whether manufacturers would be allowed to escape liability on the basis of their actions promoting "the greatest good," is here highly relevant. By hypothesis, when the Government orders products made to Government design specifications the defense here being considered is limited to those aspects of the manufacturer's product that conform to those design specifications. Whether the manufacturer will be liable for product units that do not conform to the Government design specifications—e.g., individual sticks of dynamite that contain too high concentrations of taggants—may be relatively less affected by the fact that the Government has requested or dictated the relevant design. Thus, in *Foster v. Day & Zimmerman*, 502 F.2d 867 (8th Cir. 1974) an army reservist recovered from the manufacturer of a flawed hand grenade notwithstanding the fact that the hand grenade had been made according to army design specifications.

One area in which courts have frequently addressed the possibility of a defense to tort liability based on conformance to Government-imposed design requirements involves products made to Government contract specifications. It can be argued that the defendants in these contract specification cases were not "required" by law to produce the products later alleged to be defective, in the same sense that the explosives manufacturers would be "required" to include taggants in explosives. To some extent, however, that distinction gives way under analysis. It is a fact of economic life that the companies who produce the sorts of products typically purchased in large quantities by Government cannot survive without getting their share of Government business. Moreover, as a technical matter even the explosives manufacturers are not being *required* to produce explosives containing taggants—they are "free" to decide not to sell explosives at all. Thus, the products liability cases involving the availability to producers of the "made to Government specifications" defense are relevant to the present analysis, tempered to the extent that the degree of coercion is marginally less in the contract cases. Judicial recognition of such a defense in that context provides that much stronger support for a defense in the context of a statutory taggants requirement.

A decision frequently cited for the proposition that a manufacturer will not be liable for the design characteristics of a product made to Government specifications in Littlehale v. E. I. du Pont de Nemours & Co., 380 F.2d 274 (2d Cir. 1967), aff'g 268 F. Supp. 791 (S.D.N.Y. 1967). The plaintiff in that case was a civilian employee injured by a special type of blasting cap made 13 years earlier by the defendant to Government design specifications. The district court entered summary judgment in favor of the defendant, stressing the fact that the product design was dictated by the Government. The court of appeals affirmed, emphasizing the lack of any duty to warn such as sophisticated user. (It appears the plaintiff had begun by compiling flaw design and warning theories but abandoned the first two during trial.) Subsequent decisions have tended to question whether the *Littlehale* decision actually supports the principle that a product cannot be defective by reason of those of its design characteristics that conform to design specifications dictated by the Government. In *Schwartz v. Hummel Chemical Co.*, 524 F.2d 18 (3rd Cir. 1975), for example, the court read *Littlehale* as standing for the principle that a manufacturer's duty to warn is limited to foreseeable users.

A recent decision that cites *Littlehale* for the "Government specifications is a defense" principle is *Sanner v. Ford Motor Co.*, 144 N.J. Super. 1, 364 A.2d 43 (Law Div. 1976), aff'd per curiam 154 N.J. Super. 407, 381 A.2d 805 (1977), cert. denied 75 N.J. 616, 384 A.2d 846 (1978). The plaintiff in that case was a civilian driver of a Government surplus Jeep injured in a rollover accident who claimed that the design was defective because it lacked seat belts. The trial court denied recovery as a matter of law, chiefly on the ground that the design conformed to Government specifications and the special purposes for which the military originally had ordered and purchased it and therefore was not defective. And in *Hunt v. Blasius*, 55 Ill. App. 3d 14, 12 Ill. Dec. 813, 370 N.E.2d 617 (1977), aff'd 74 Ill.2d 203, 23 Ill. Dec. 574, 384 N.E. 368 (1978), the court ruled as a matter of law for the defendant manufacturer and installer of a roadside signpost whose allegedly defective design conformed to specific design specifications imposed as a condition of purchase by the State.

Several possible limitations on the availability of these precedents to explosives manufacturers in the present context must be noted. First, an exception to the general rule of availability would almost certainly be recognized in cases where the manufacturer knew or had reason to know that the Government specifications were dangerously deficient. (See *Ryan v. Feeney & Sheehan Building Co.*, 145 N.E. 321 (N.Y. 1924).) Admittedly, cases recognizing this exception have tended to be ones in which the defendant could be said to have "volunteered" its services and in the cases envisioned by courts to fall into the exceptional category the Government agencies are probably ignorant of the deficiencies of the designs. Neither of these circumstances appears to be present in connection with the inclusion of taggants and thus the exception to the availability rule probably does not apply.

A second caveat is based on the fact that both the *Sanner* and *Hunt* decisions appear distinguishable on their facts from the taggants case on another ground besides the fact that the design requirements were not imposed by statute. In those cases and most of the others that have recognized the nonliability rule, the Government agencies purchased the products exclusively for their own use. To impose liability on the product suppliers would be in effect to impose liability on the governmental agencies by way of an increase in prices paid for products designed specifically and exclusively for Government use. The latent assumption here is that the Federal Government will not limit the application of the taggants requirement to products for its own use. Thus, were explosives manufacturers held liable for harm caused by the use of taggants, the accident costs would be shared by all users of explosives. Government operations would be singled out to bear the costs of taggant-related accidents.

It remains to consider the significance of the fact that the taggants requirement is imposed by statute rather than by contract. In this connection, one possible source of confusion must be eliminated. A long recognized rule in tort law is that compliance with Government safety regulations is no bar to liability for one's negligent conduct. (See Restatement of Torts, Second § 288(c).) That proposition, however, is very different from the one here being considered. The rule in 288(c) relates to the situation in which the Government establishes a minimum level of safety precautions and a reasonable person would take additional precautions. The rule of nonliability being considered here relates to the very different situation in which the Government mandates action which a court would in the absence of the mandate find to be negligent. It is one thing to hold an actor liable for not being safer than the Government minimally requires him to be. It is quite another to hold an actor liable for a dangerous course of conduct which his Government requires him to take. In the first case, the governmentally imposed regulation leaves the actor free to decide whether to act more safely than the Governmust expose in the service the requirement does not leave him free to make that decision.

The main difference theoretically between the Government imposing design specifications by contract and by statute lies in the legislature's power to change the common law by the latter but not the former method. Thus, when taggants are required by statute to be added to explosives, in addition to considering whether it is fair to hold the defendant liable for complying with the requirements of the Government, courts must consider whether the legislature has by implication changed the common law rules that determine liability. Viewed properly, the question is whether the taggant requirement reflects a legislative judgment on the same issue that the courts are being asked to resolve in the liability action. If it does, then courts are required (putting constitutional aspects to one side for the moment—see pp. 222-223 *infra*) to give deference to the legislative judgment. In many instances of Government-imposed design changes, a legislative judgment that the design changes will increase the safety of those affected by the product could be inferred from the fact of the mandated change. To hold a defendant liable in tort for doing something the legislature has decided is safer than not doing it would be contradictory.

Is the taggant requirement similar to these other safety requirements? That is, does that requirement reflect a legislative judgment that their inclusion reduces — or at least does not increase — the risks of accidental explosions? Given the legislative history of the measure, it cannot be argued that it does not reflect such a judgment. Instead, it can be argued that the taggant requirement reflects a legislative decision actively to increase slightly the risks of accidental explosions in the interests of increasing public safety against intentionally criminal explosions. (See discussion pp. 211-212 *supra*.) If the courts were to view the taggant requirement in this way, presumably they would be free to address for themselves the question of liability for those increases in risks.

Assuming that some courts, at least, do not feel themselves bound by an implicit judgment by the legislature regarding the reasonableness of taggant inclusion from the standpoint of user safety, whether the "Government regulations" defense will be available in taggant cases brought against explosives manufacturers will probably depend on whether these courts view products liability primarily as a means of deterring unreasonable conduct or as a means of compensating innocent accidental victims. If the focus is on deterring unreasonable conduct, the defense will probably be available; after all, holding manufacturers liable will not cause them to violate Federal law. On the other hand, if the focus is on compensation, it is more difficult to see the direct relevance of the taggants requirement. If manufacturers are liable to pay for harm caused to innocent victims by taggants products, in the end society will bear the costs through higher prices paid for the goods and services whose production requires the use of explosives. To the extent that members of this larger segment of society are generally the ones who also benefit from the anticriminal aspects of taggants inclusion, the results of imposing liability may seem fairer to some courts than the results of denying liability. To some extent, even a denial of liability would cause accidental explosion costs to be reflected in the prices of goods and services the production of which is dependent on the use of explosives. Commercial users of explosives, for example, presumably insure themselves against portions of the costs of accidental explosions, who pass the insurance costs on to their customers. And commercial users are liable to others injured by their activities. (See p. 210, *supra*.) However, the imposition of liability on explosives manufacturers would seem to accomplish the cost-spreading objective more fully.

One further issue must be addressed in connection with the possibility of a "Government specifications" defense. Because the inclusion of taggants would be required by Federal law, courts applying State law rules of products liability would be required to determine whether the Federal law had "preempted" — superseded State law. The substance of such an analysis would be essentially similar to the analysis just described when a State statute is involved. The major difference would be that the Federal courts would become involved in reviewing the State court decisions interpreting the intent of Congress.

The Efficacy of Warnings and Disclaimers

It is most unlikely that explosives manufacturers would be allowed to exempt themselves from liability by disclaimers included in their sales contracts. (See pp. 204-205 *supra*.) Would warnings fare any better in court? That is, would manufacturers be allowed to escape liability by warning users that their explosives contain explosive-identification taggants? Again, the answer here is likely to be in the negative. It will be recalled from an earlier discussion that warnings serve to apprise persons of risks which they are in a position to avoid. (See p.

207, *supra.*) Presumably users of explosives containing taggants would not be in a position to avoid taggant-related risks by modifying their use of explosives. In effect, manufacturers would be warning users that flaws exist which may, more or less on a random basis, cause harm. Viewed in this light, such "warnings" appear to be more like "disclaimers in warning clothing," and presumably would not be given legal effect by many courts. However, it is to be expected that sales of explosives would be accompanied by such "warnings," and it cannot be said with certainty that some courts would not bar recovery on that basis. (Or perhaps on the basis, equally dubious on these facts, that the users "assumed the risks" of accidental explosions. See p. 208, *supra.*)

Changes in Explosives Handlers' Exposures to Liability

It will be recalled from an earlier discussion that professional users and handlers of explosives are held to particularly high standards of care, approaching strict liability in some jurisdictions. (See p. 210, *supra.*) The addition of identification taggants could have four types of effects on their exposures to liability. First, to the extent that they are already held strictly liable, an increased incidence of accidental explosions would as a practical matter increase their strict liability. Second, to the extent that the inclusion of taggants were to require special care in handling explosives, users would presumably be exposed to greater negligence-based liability. Third, the inclusion of taggants would facilitate tracing explosives detonated by terrorists (or by children into whose hands the explosives came) to their sources, opening up the possibility of an argument of inadequate care taken to prevent the escape of such dangerous instrumentalities. And lastly, the presence of taggants might provide the basis for users of explosives to escape negligence-based liability by blaming accidental explosions on the taggants, and might allow explosives users to succeed in indemnity actions against explosives manufacturers.

Exposure to Liability of Taggant Manufacturers

Claims That the Taggants Caused Accidental Explosions—Proof of Defect

The question of whether plaintiffs will succeed in proving that taggants caused accidental explosions was addressed in the preceding section, and the analysis will not be repeated here. Assuming that some plaintiffs succeed in linking taggants to accidental explosions, what will be the taggant manufacturers' exposure to liability? Presumably, if a plaintiff proves that a particular batch of taggants was abnormal in some way—perhaps the pieces were too big or varied too greatly in size—he would have a good chance of reaching the trier of fact with a claim based on a flawed component. (See pp. 207-208, *supra.*)

If no such proof of abnormal taggant configuration were available, the plaintiff would be left to proceed on the basis that the taggant manufacturer supplied a defectively designed component part. The defendant would argue that it is in the same position as the supplier of any basic ingredient supplied in bulk to a product manufacturer. If the combination of ingredients turns out to be dangerously defective, it is the product manufacturer's and not the component part manufacturer's responsibility. It will be recalled from an earlier discussion that suppliers of traditional ingredients of explosives would probably succeed with such an argument. (See p. 208, *supra.*) However, courts may view the taggant manufacturer as being closer to the manufacturer of the machine component in the *Dunson* decision discussed earlier (p. 209, *supra.*). The defendant in that case was held liable for a "dangerous combination of components" on the basis of its knowledge of the dangers and its involvement in manufacturing a component designed specifically for use in the final product.

In response to plaintiffs' attempts to draw them into the orbit of responsibility for the (presumably) dangerous and defective explosives containing taggants, taggant manufacturers could be expected to argue that they did not design their product specifically for use in explosives, but rather as a product of many and varied industrial applications. Viewed in this manner, they would appear closer to the suppliers of basic general-purpose ingredients of explosives. They could also be expected to rely on the disclaimers included in their contracts of sale, which, when reviewed in light of this analysis, appear consciously designed to "build a record" in support of their assertions of a general-purpose product. However, it might be shown that taggant manufacturers would never have gotten into the manufacture of taggants in the first place without the prospect of their being required to be included in explosives, notwithstanding their protestations to the contrary. (This writer lacks information on this issue—he advances these considerations merely as speculations.)

Claims That Detection Taggants Failed to Function Properly

On the assumption that it could be proved that detection taggants failed to function properly (see pp. 213-214, supra), plaintiffs injured because of such failures might have causes of action against the manufacturers of those taggants. (For a discussion of the liability of component manufacturers generally see pp. 207-208, supra.) Some of the difficulties facing plaintiffs in such actions have already been described. (See pp. 213-214, supra.)

Significance of the Fact That Explosives Manufacturers Are Required by Law to Include Taggants

Most of the legal material relevant to this issue is contained in the earlier treatment of explosives manufacturers' liabilities which will not be repeated. (See pp. 214-215, supra.) At least two factual differences in the positions occupied by taggant manufacturers in contrast to explosives manufacturers deserve attention: 1) taggant manufacturers, unlike explosives manufacturers, are not required by law to be involved with taggants; and 2) taggant manufacturers, unlike explosives manufacturers, exert control over the design of the taggants. Do these differences entitle the taggant manufacturers to be taken out of the rule of nonliability that may apply to explosives manufacturers based on the fact of Government regulation?

In attempting to persuade a court that the nonliability rule based on Government specifications ought not to extend to taggant manufacturers (even if the court decides to extend it to explosives makers) a plaintiff might argue as follows: "No one, including the Government, urged (much less required) taggant manufacturers to begin to develop such a product. Sensing a substantial profit to be made, these manufacturers on their own developed the taggant designs in question, patented them, and then worked diligently to persuade Congress to require them in explosives. In the cases relied upon by the defendants (see pp. 214-215, supra) the Government went to the producers and requested them to do specifically described projects. The Government did not exactly require the manufacturers to produce the products, but it is an economic fact of life that producers of such products rely for their survival on getting their share of Government contracts. (Indeed, as a technical matter explosives manufacturers are not required to include taggants — they are "free" to choose to go out of business.) Moreover, in the cases relied on by the defendants, the Government made all the significant design choices. If taggant manufacturers are allowed to invoke the nonliability rule the court will have extended the shelter of "we had no control over the design" to companies that in fact dreamed up the idea of explosives taggants in the first place, controlled completely their development and ultimate design, and then with substantial effort convinced Congress to require other manufacturers to include them in their products under penalty of law."

The writer wishes to make clear that in advancing this argument hypothetically he takes no position regarding its intrinsic merit. Whether courts would listen to such an argument is a different question. On balance this writer is inclined to believe some of them, at least, would accept it, and not allow the taggant manufacturers to argue that they should not be liable because they made the taggants to Government specifications.

The Efficacy of Disclaimers

It is likely that the taggant manufacturers' disclaimers would not be given effect as disclaimers in actions brought by injured plaintiffs. (See pp. 204-205, supra.) Whether they would be given effect in the context of contribution or indemnity actions between themselves and explosives manufacturers is less clear. It will be recalled from an earlier discussion that business entities dealing from equal bargaining positions are often allowed by courts to allocate liabilities between them. (See p. 205, supra.) However, it is not clear that the bargaining positions in this instance are equal, given the fact that the explosives manufacturers cannot go without taggants. In a sense, the taggant manufacturers would have the explosives manufacturers "over the barrel" and courts might refuse to give effect to disclaimers for that reason.

Returning to the Initial Factual Assumptions

The objective here is to return briefly to some of the factual assumptions made at the beginning of this liability section to consider the implications of alternative assumptions. The first assumption, that Congress will require the inclusion of both identification and detection taggants, is omitted. If detection taggants are not required to be included, it may reasonably be assumed they will not present products liability problems. The next assumption made earlier, that Congress will not provide immutities or other legislative adjustments of liabilities will be treated separately in the next section.

What If the Designs of the Taggants Are Not Specifically Described by Regulation?

It will be recalled from an earlier discussion that two types of standards are available with which to describe the taggants that would be required to be included in explosives — design standards and performance standards. (See pp. 210-211, *supra*.) If performance standards were used in the relevant regulations, their major impact would be in connection with the issue of whether the manufacturers of explosives and taggants could argue against liability on the ground that the Government required taggants to be included in explosives. (See pp. 214-215, *supra*.) Performance standards would give the manufacturers greater control over the designs of the taggants to be included and would weaken the availability argument. Of course, from the explosives manufacturers' standpoint, control in this context may be illusory if only one taggant manufacturer's product meets the Government performance standards and it is not feasible for the individual explosives manufacturers to develop their own. At least from the taggant manufacturers' standpoint, however, performance standards would give them even more control — and attendant liability — compared to the situation that would be presented by design standards.

What If Congress Includes Black and Smokeless Powders in the List of Explosives Required to Contain Taggants?

The major source of added difficulty in this circumstance is the fact that these powders, unlike most of the other explosives considered to this point, are "consumer products" in the normal sense of that term — i.e., consumers purchase and use these powders in small quantities in connection with a fairly broad range of sporting and recreational purposes. Generally speaking, courts have traditionally been more willing to impose liability on the makers and sellers of consumer products than on the makers of other types of products. Moreover, it may reasonably be assumed, at least for purposes of this analysis, that including taggants in loose-packed powders presents greater technical problems — e.g., physical separation of the taggants from the powders — than would be the case with solid-packed explosives such as dynamite. The combination of these two factors — a consumer product that poses greater technical problems — might very well increase the exposure to liability of both explosives and taggant manufacturers as a practical matter.

One major battleground, and particularly a greater one than in connection with the use of solid-packed taggant-treated explosives by professional users (see pp. 216-217, *supra*) would be failure to warn. Persons (including consumer bystanders) injured during the course of consumer use of taggant-treated powders would argue that they were not sufficiently warned of the risks accompanying such use, and a percentage of such cases could be expected to reach the jury. (On the subject of failure to warn, see generally p. 207, *supra*.) Moreover, consumers would include in such cases claims based on product flaws (e.g., scattered abnormally high concentrations of taggants, or wrong size taggants — see generally pp. 206, 213, *supra*) and defective product designs (taggants are defectively designed component parts) (see generally pp. 206-207 and 211-213, *supra*), and a percentage of these claims could be expected to succeed.

What If Congress Decides That Explosives Containing Taggants Pose Socially Acceptable Levels of Risk?

The change in the assumption here is that instead of determining that taggants pose no practical risks of accidental explosions — i.e., are "safe" for normal handling — Congress determines that the levels of risk presented by including taggants are not insignificant but are nevertheless socially acceptable — i.e., that some explosives will accidentally detonate but that the antiterrorism benefits to society derived from including the taggants outweigh the costs of accidental explosions. With this hypothetical change in the assumption, the exposure to liability of explosives and taggant manufacturers (absent judicial recognition of the defense of governmental coercion and absent a specific immunity provided by Congress—see the next section) also would almost certainly increase over what it would have been based on the former assumption. It will be recalled from an earlier discussion that even a finding by Congress that taggants are "safe" is unlikely to insulate manufacturers from liability as a practical matter (see p. 215, *supra*.) By hypothesis, plaintiffs would be helped more if Congress were to concede in its findings the existence of a measurable but acceptable risk of accidental explosions. The question of whether courts would allow manufacturers to rely upon the social acceptability of the risks in arguing against liability was considered earlier (see pp. 211-212, *supra*) and that analysis will not be repeated. On the strength of the earlier analysis, it is unlikely that an explicit declaration by Congress that the benefits to society outweigh the risks of accidental explosions would change the courts' reactions to this aspect of the problem.

What If Taggant Manufacturers Sell Their Products to the Federal Government Which in Turn Sells Them to Explosives Manufacturers?

In an earlier discussion of the significance of the fact that explosives manufacturers are required to include taggants, it was recognized that in most of the cases in which manufacturers appear to have been exempted from liability on that basis, the Government actually purchased the products later alleged to be defective. (See p. 216, supra.) Superficially at least, it would appear that both explosives and taggant manufacturers would be able to equate themselves more easily with the sellers in those cases were the Government to purchase the taggants and then resell them to explosives manufacturers.

One basis for questioning whether it would be that simple, however, is the other half of the earlier distinction between the precedents and the taggant situation — i.e., the Government agencies in those cases originally purchased the products for their own use. It could plausibly be argued that there is a significant difference between the Government purchasing specially designed products for its own use and later allowing the public to gain access to those products, on the one hand, and the Government acting merely as a conduit between private interests, on the other. To impose liability in the first situation arguably would reduce unduly the ability of the Government to obtain at reasonable costs products specially suited to its operational — e.g., military— needs. To impose liability in the second situation would not have those consequences, assuming that the Government passed on its costs to the explosives manufacturers. Thus, it can be argued that to refuse to impose liability merely because the Government acts as a sales conduit would be to exalt form over substance.

If the Government were to act as a sales conduit for the taggants, would the Government be exposed to products liability? The answer here would almost certainly be in the negative, given the availability of sovereign immunity. It has been held that strict products liability actions do not fall within the consent to suit provisions of the Federal Tort Claims Act. (See In Re Bomb Disaster At Roseville, Cal., on April 28, 1973, 438 F. Supp. 769 (E. D. Cal. 1977).) And were a plaintiff to pursue a claim in negligence on the basis of inadequate testing or mistake in judgment in deciding to include taggants, the claim would almost certainly come within the preclusion of liability for the "exercise or performance or the failure to exercise or perform a discretionary function or duty." (28 U.S.C.A. § 2680(a).)

ASSUMING THAT THE TAGGANTS REQUIREMENT WILL INCREASE THE PRODUCTS LIABILITY EXPOSURES OF THE EXPLOSIVES INDUSTRY, WHAT ADJUSTMENTS OF THOSE EXPOSURES MIGHT CONGRESS CONSIDER MAKING?

The purpose here is not to make recommendations regarding whether or how legislatively to adjust the exposures to liability of the parties affected by the proposed taggants requirement but rather to explore the major alternatives available to Congress in this regard and to explore briefly the significant implications of each. In developing those alternatives in the sections that follow, the underlying assumption will be that Congress is chiefly concerned with the possible allocation of accidental explosions costs generated by the inclusion of normal concentrations of properly manufactured taggants in explosives, and is ready in any event to allocate the accident costs of abnormal concentrations and improperly manufactured taggants —the sorts of product "flaws" in the traditional sense of that term—to the manufacturers and sellers of taggants and explosives responsible for such abnormalities.

Congress Could Decide to Shift the Accident Costs of "Normal" Taggant Inclusion to the Federal Government

The main policy argument in support of this alternative is that the costs of accidental explosions caused by the inclusion of normal concentrations of properly manufactured taggants are costs directly attributable to the decision of Congress to require such inclusion in the interests of public safety, and therefore they should be borne by the Federal Government and spread generally to the public through the tax system. At least three basic variations of this alternative are available:

The Existing Tort System Remains Unchanged; When Manufacturers' Liability Is Based on Normal Taggant Inclusion They May Obtain Indemnity From the Government

Under this approach manufacturers (and other commercial sellers) would be the defendants against whom the actions would initially be brought. In cases in which they are held liable in tort based upon the inclusion of normal concentrations of properly manufactured taggants they would be indemnified, thus shifting the liability losses to the Federal Government. A number of questions may be raised concerning the efficacy of this approach, among which are the following: 1) manufacturers would still be open to the expense of defending these actions—would such expenses be reimbursed? 2) How would the basis of the defendant's liability be determined? Might Congress require a special verdict mechanism in all such cases—i.e., a specific finding by the trier of fact as to the role played by taggants in the explosion? 3) Would every case have to go to trial? What if settlements were reached? 4) Would such an approach create additional financial incentives favoring a finding of taggant involvement that manufacturers would manipulate the trial process to help assure such a result? 5) Would triers of fact, some of whom can be assumed to know of the indemnity plan, be tacitly encouraged to "blame the taggants" in cases involving accidental explosions?

One further issue that is inherent in indemnity actions which would have to be addressed is that of collateral estoppel. A decision in the action against the manufacturer that normal concentrations of properly manufactured taggants did not cause the explosion would preclude relitigation of that factual issue in an indemnity action against the Government. (See Park Lane Hosiery Co., Inc. v. Shore, 439 U.S. 322, 58 L. Ed. 2d 552, 99 S. Ct. 645, (1979).) But a finding that a normal concentration of properly manufactured taggants caused the explosion would not necessarily bind the Government in an indemnity action. A sensible statutory procedure involving indemnity actions against the Government would almost certainly include consent by the Government to be bound by the factual determinations in the actions against the manufacturers.

Immunity From Liability Is Granted to Members of the Explosives Industry for All Accidental Explosions; Plaintiffs Bring Actions Against Government; Government May Obtain Indemnity From Manufacturer If "Normal Taggant Inclusion" Is Not the Basis of Liability

This is the reverse of the variation considered in the preceding section, and resembles somewhat the approach to the liability question adopted recently in the National Swine Flu Immunization Program of 1976 (42 U.S.C.A. § 247b(j)-(l) (1976).). In theory it reaches the same allocations of liability as the preceding variation, but the actions are brought in the first instance against the Government, not the explosives industry.

One significant difference between the circumstances surrounding the Swine Flu Program and the circumstances surrounding the inclusion of taggants in explosives relates to the relative significance of causal factors other than the Government-instigated activity. In connection with the Swine Flu program, it could be assumed that a majority of the cases brought successfully by injured plaintiffs would not involve indemnity — i.e., that a majority of those persons injured were injured as a result of the inherent risks of the Program rather than the negligence of the manufacturers. With the taggants program, the situation may be quite the reverse. Here it might be assumed that a relatively small percentage of accidental explosions are actually attributable to the normal inclusion of taggants. If that is the case, then the approach here being considered would, in contrast to the Swine Flu program, in most cases send plaintiffs initially to the "wrong place" from which to seek relief.

Two results of this misdirection of focus, neither particularly desirable, might occur. Either taggants would typically be exonerated in the actions brought against the Government, in which case indemnity actions would become routine and the associated transaction costs a source of waste, or the triers of fact in the actions against the Government, sensing something of a "giveaway," would tend to blame the taggants in many more cases than could be supported on the data. In theory, of course, the latter circumstance would not arise. In practice it could well be a real possibility.

The problem of whether findings in actions against the Government would be binding in indemnity claims against manufacturers would have to be resolved differently from the way it would be resolved when suits are brought initially against manufacturers. Under the variation discussed here, the Government could not consent on behalf of the manufacturers that they be bound. But a statutory provision enabling the making of the appropriate members of the explosives industry parties to the action could be worked out.

Limited Immunity From Liability Is Granted to Members of the Explosives Industry for Accidental Explosions Caused by Normal Taggant Inclusion; Government Is Liable for Explosions Caused by Normal Taggant Inclusion

This variation is a combination of the two preceding and could be accomplished by either of two procedures. One method would be for plaintiffs to bring ordinary legal cases against the Government and others against the appropriate members of the explosives industry. One drawback to this is the inefficiency associated with keeping two separate actions if it turns out that the plaintiff sued the wrong defendant first. A further problem is that once the indemnity idea is abandoned, a theory which would make the findings in the first trial binding on the defendant in the second would be more difficult to work out.

The second method would be for the plaintiff to sue both the Government and the appropriate industry members in a single suit. This would have the advantage of bringing all the parties together in a single proceeding. But if the suits were brought in Federal court, accommodations would have to be made with the existing rules of diversity jurisdiction and jurisdictional amount. For the action to be brought in State court, Congress would have to consent to such suits.

Congress Could Decide to Shift the Accident Costs of Normal Taggant Inclusion to Explosives Users

The main policy argument in support of this alternative is that the actual risks posed by normal inclusions of taggants in explosives may be significantly smaller than the practical increases in manufacturers' exposure to liability resulting therefrom, causing an unfair shifting to manufacturers of accident costs that have been traditionally and arguably should continue to be borne by the users of explosives. Under this alternative, when commercial users or their employees are injured because of normal taggant inclusion, the losses would remain where they fall due to the accident. When innocent bystanders are thus injured, the users would presumably be strictly liable in tort. (See p. 210, supra.) Admittedly, explosives users are apt to blame for the very few accidental explosions that are in fact caused by normal taggant inclusion, but there is no practically feasible way to allow them to seek recovery for those accidents without unfairly shifting much greater accident costs unrelated to taggant inclusion to explosives manufacturers. (Obviously, the greater Congress's confidence in the safety of normal taggant inclusion, the more attractive this alternative becomes.)

The following variations on this theme deserve mention here.

The Existing Tort System Remains Unchanged Except That Congress Establishes a Presumption That Taggants Do Not Cause Accidental Explosions Subject to Being Rebutted by Proof of Abnormal Taggant Concentrations or Improper Taggant Manufacture

Under this variation, plaintiffs would succeed in all of the cases in which they have traditionally succeeded under existing law and would succeed in cases in which they can prove a "taggant flaw" in the literal sense of that term — i.e., cases in which they can prove that the concentration of taggants was too high (or low, if that were to cause the explosion) or that the taggants themselves were abnormal in some way. The major legal difficulty with this approach would be presented in the form of attacks by injured plaintiffs against such a provision on the ground that it constitutes an unconstitutional deprivation of rights in violation of due process of law. The recent Supreme Court decision in *Usery v. Turner Elkhorn Mining Co.*, 428 U.S. 1 (1976) however, would seem to support the validity of such a presumption. The plaintiffs in that case were coal mine operators challenging on due process grounds the constitutionality of the Coal Mine Health and Safety Act. The Supreme Court upheld the Act's validity, including the establishment of an irrebuttable presumption that certain coal miners' lung diseases were work-related, concluding that due process requirements are satisfied in connection with liability-creating presumptions if there is "a rational connection between the fact proved and the ultimate fact presumed." (428 U.S. at 4.)

Admittedly the "rational connection" to which the court refers would become strained in the present context if Congress were not factually to conclude that normal taggant inclusion was "safe" for normal handling of explosives. But assuming that Congress views as remote the chances of normal concentrations of taggants causing explosions a presumption of no causal connection should withstand judicial scrutiny. "When it comes to evidentiary rules to motivate and within specialized judicial competence or completely common place," the Court concluded in *Usery v. Turner Elkhorn Mining Co.* [supra], "it is primarily for Congress to amass the stuff of actual experience and cull conclusions from it." (428 U.S. at 33-34 quoting *United States v. Gainey* 380 U.S. 63,67 (1965).)

Congress Could Grant to Manufacturers Immunity From Tort Liability for Accidental Explosions Caused by Normal Taggant Inclusion

If the "rebuttable presumption" approach were believed to present constitutional problems of the sort considered in the preceding section, this variation might provide an alternative approach to accomplishing the same objective without reliance on presumptions. Thus, if Congress were ready to accept the policy argument advanced at the outset of this section it might be more straightforward to speak in terms of an immunity granted on the basis of a policy judgment rather than a presumption based on a factual judgment. Of course, plaintiffs could be expected to attack this alternative on the ground that it denies to them the constitutionally guaranteed right to equal protection of the laws. An attack of this sort was recently brought in Federal court against a somewhat similar provision in the Federal law limiting the liability of nuclear plant operators.

In *Duke Power Co. v. Carolina Environmental Study Group*, 438 U.S. 59 (1978), the Federal no-fault compensation scheme created for the benefit of victims of nuclear accidents resulting from the operation of federally licensed nuclear power generation facilities was challenged on due process and equal protection grounds. The district court held the statutory ceiling of $560 million on liability from one accident to be, inter alia, violative of the equal protection requirement because the statute "place[s] the cost [of the encouragement of nuclear power] on an arbitrarily chosen segment of society, those injured by nuclear catastrophe." (431 F. Supp. 203 (W.D.N.C. 1977).) The U.S. Supreme Court reversed, holding the ceiling on liability to be a "classic example of an economic regulation." (438 U.S. at 83.) The Act was rational, according to the Court, in view of Congress's purpose of encouraging private development of nuclear energy and there was "ample justification for the difference in treatment between those injured in nuclear accidents and those whose injuries are derived from other causes." (438 U.S. at 93-94.) Although the facts are somewhat different (a limited remedy was available to injured plaintiffs under applicable legislation) it can be argued that the Duke Power decision supports extending the immunity described herein.

Congress Could Decide to Shift the Accident Costs of Normal Taggant Inclusion to Manufacturers of Taggants and Explosives

Congress could reach at least two conclusions that would support this alternative. First, Congress could assume that the costs of these taggant-related accidental explosions will be passed on by the manufacturers to their customers in the form of increases in prices and conclude that such a distribution of these costs is appropriate and second, Congress could assume that the manufacturers are in positions of control over the techniques of design and manufacture affecting the levels of risks presented by normal taggant inclusion, and conclude that imposing liability will pressure manufacturers to exercise their control in ways to accomplish reductions in those risks.

A starting point for accomplishing these objectives would be for Congress to grant no immunities, nor extend any rights of indemnity to manufacturers of taggants and explosives. In addition, some or all of the following changes in existing law might be considered.

Nonviability Based on the Fact of the Government's Involvement Could Be Eliminated Legislatively

It will be recalled that in cases involving taggants, manufacturers may have available to them arguments that they should not be liable due to the fact that taggants are required by law to be included in explosives. (See pp. 214-218, *supra*.) If Congress concludes that these accident costs should be borne by the manufacturers, the possibility of such a defense could be eliminated legislatively.

Manufacturers' Liability for Accidental Explosions Caused by Taggants Could Be Established Legislatively

It will be recalled from an earlier discussion that some courts, at least, could be expected to hold the manufacturers liable in cases where the plaintiff succeeds in proving that the taggants caused an accidental explosion. (See pp. 211-213, *supra*.) However, to clear up any doubt on the question, Congress might consider making it clear in the statute.

A Presumption That Accidental Explosions Are Caused by Taggants Could Be Established Subject to Being Rebutted by Proof of User Mishandling

This would be a drastic change in existing law which, in combination with the preceding two, would practically ensure that every plaintiff injured in an accidental explosion would reach the trier of fact regardless of the actual cause of the explosion. The practical effect of this change in existing law would be to make manufacturers simple insurers of the safety of those using and affected by explosives. (For a brief description of the basis for constitutional challenge of this change by the manufacturers, see pp. 222-223, *supra*.)

The Question of Indemnity and Contribution Between Taggant Manufacturers and Explosives Manufacturers Could Be Addressed Legislatively

Especially if the alternative of shifting the costs of manufacturers were adopted, Congress should consider the possibility of establishing specific rules governing questions of indemnity and contribution between these manufacturing groups. (*Cf.* pp. 211-213 and 217, *supra*.) On the basis of "who profits?" and "who controls?" the activity in question, taggant manufacturers might be required to indemnify explosives manufacturers.

Congress Could Decide to Divide the Costs Among the Interested Parties, Apportioning Such Costs in a Variety of Ways

The possible variations under this alternative are numerous and will not be explored in their variety. One possibility, however, deserves mention, if for no other reason than the fact that it has become something of a favorite with State legislatures in addressing areas of tort liability such as medical malpractice perceived to be in various stages of "crisis." Congress could decide to place a dollar limit on claims arising out of accidental explosions found to have been caused by normal incidence of taggants. Were this approach adopted, it would in effect divide the costs of such accidents between manufacturers and users/victims.

SUMMARY

Exposure of the Explosives Industry to Products Liability Under Existing Law

Liability of manufacturers and other sellers of explosives: Basically, the same rules of liability that apply to manufacturers and commercial sellers of other products apply to manufacturers and commercial sellers of explosives. Defendants are liable on the basis of negligence, breach of warranty, misrepresentation, and strict liability in tort. Two fact patterns predominate in actions against explosives manufacturers: those involving product flaws and those involving failures to warn. In product flaw cases plaintiffs may rely on strict liability in most jurisdictions; in failure to warn cases a basic negligence analysis is most often employed. Two technical characteristics unique to explosives cases account for the somewhat different judicial treatment afforded these cases compared with products liability cases generally. First, explosives invariably "self-destruct" during use, forcing plaintiffs to rely to an unusual extent upon circumstantial evidence of product flaws. And second, explosives are not "consumer products" in the usual sense of that term—the typical purchasers and users of explosives are presumably experienced professionals. This second characteristic tends to affect negatively not only the plaintiff's opportunity to try to prove the existence of a product flaw, but also the likelihood of his succeeding with an argument that the defendant failed adequately to warn of hidden dangers.

Liability of manufacturers and other sellers of explosive components.—"Components" in the present context is synonymous with ingredients. Manufacturers and other commercial sellers of explosive components are theoretically liable (and in most States, strictly liable) for flaws in their products, but in practice it is difficult to attach such liability in most cases. Although sellers of components in other product areas have been held liable both for defective designs and failure to warn, the factual bases of such liability—reliance by others on the component seller's unique knowledge and judgment regarding the risks associated with uses of its product—are not typically present in situations in which basic, general-purpose chemical compounds are sold in bulk to explosives manufacturers.

Liability of manufacturers and other commercial sellers of explosives accessories.—"Accessories" refers to products normally used in connection with explosives, including blasting caps and fuses. When the injured plaintiff can prove that he was injured in an accidental explosion due to a flawed accessory, most jurisdictions will hold the commercial sellers of that accessory strictly liable. However, as a practical matter proof of physical defect is difficult, especially with respect to blasting caps. A number of suits have been brought on the basis of the defendant's failure to warn. When these manufacturers fail adequately to warn of the hazardous characteristics of their products, they are held liable to users injured by that failure. Judicial reactions to arguments that blasting cap manufacturers should warn children and other incompetent users that their products are explosive have been mixed. One court not only recognized such a duty but suggested that the entire blasting cap industry, together with their trade association, could be joined as defendants in a single action.

Liability of commercial transporters and handlers of explosives.—Commercial transporters, handlers, and users of explosives are subject to strict liability for harm to persons or property caused by accidental explosions.

How Would These Exposures to Liability Change If Congress Required the Inclusion of Taggants in Explosives?

Changes in explosives manufacturers and sellers exposures to liability.—Technically, normal concentrations of taggants pose questions of product design rather than product flaws. However, taggants that cause accidental explosions are functionally quite flawlike, and some courts can be expected to treat them like flaws. Thus, unless the defendants are permitted to rely on arguments of governmental coercion (a question to be addressed shortly), their exposure to liability will be increased to the extent that plaintiffs can prove that taggants caused accidental explosions. Expert testimony supporting such a causal relationship could take two basic forms: 1) testimony that a normal concentration of taggants caused the explosion, and 2) testimony that an abnormal concentration of taggants caused the explosion. It is likely that plaintiffs will, in appropriate cases, find experts willing to offer both types of testimony.

It is difficult to predict the exact significance courts will attach to the fact that defendant manufacturers are required to include taggants in explosives. A strong argument can be made, supported by precedent, that this element of governmental coercion should constitute a defense. However, the situation surrounding the inclusion of taggants may be sufficiently different from the situations in prior cases to allow courts to impose liability. In any event, because the taggants requirement is imposed by Federal law, courts will be faced with the question of whether State laws governing tort liability have been preempted.

The exposure to liability of taggant manufacturers.—If the plaintiff can prove that a particular batch of taggants was flawed, causing an accidental explosion, the taggant manufacturer will probably be liable. Whether taggant manufacturers will be liable for explosions caused by "normal" taggants depends on whether courts view taggants as components specially designed for inclusion in explosives exclusively, or whether courts view taggants as general purpose products suitable for a range of different applications, not all of which are narrow sarily dangerous. On balance the former approach seems more plausible and therefore taggant manufacturers may be exposed to liability to injured victims of taggant-caused accidental explosions. Although courts are unlikely to give effect to disclaimers vis-a-vis injured parties, the question of whether they will give effect to disclaimers vis-a-vis explosives manufacturers is more in doubt.

Whether courts will allow taggants manufacturers to depend on the basis that taggants are required by Federal law to be included in explosives is not clear. It can be argued persuasively that taggants manufacturers should not be allowed such a defense even if courts were to make that defense available to explosives manufacturers.

What Adjustments to These Exposures to Liability Might Congress Consider Making?

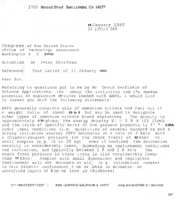
Congress could decide to shift the accident costs of "normal taggant inclusion" to the Federal Government. Three approaches to this end might be considered: 1) allow defendant companies held liable in tort actions because of the inclusion of normal concentrations of taggants to seek indemnity from the Government; 2) grant to the companies immunity from tort liability for allegedly defective explosives, allow all actions based on allegedly defective explosives to be brought against the Government, and then allow the Government to seek indemnity from the companies when "normal taggant inclusion" is not the basis of the Government's liability; or 3) grant immunity to the companies limited to liability for accidents caused by "normal taggant inclusion," and allow those cases to be brought against the Government.

Congress could decide to shift the accident costs of "normal taggant inclusion" to explosives users. Two approaches to accomplish this end might be considered: 1) Congress could create a presumption that taggants do not cause accidental explosions, subject to being rebutted by proof of abnormal taggant concentrations or improper taggant manufacture; or 2) Congress could grant to manufacturers and users immunity for accidental explosions caused by normal taggant inclusion.

Congress could decide to shift the accident costs of "normal taggant inclusion" to manufacturers of taggants and explosives. A range of alternatives are available to accomplish this end, among them: 1) nonliability based on the fault of Government agencies could be eliminated legislatively; 2) manufacturers' liability for accidental explosions caused by taggants could be established legislatively; 3) a presumption that accidental explosions are caused by taggants could be established legislatively, subject to being rebutted by proof of user mishandling; and 4) the question of indemnity and contribution between taggant manufacturers and explosives manufacturers could be addressed legislatively.

Congress could divide the costs among the interested parties. This objective could be accomplished by placing a dollar limit on claims arising out of accidental explosions found to have been caused by normal taggant inclusion, effecting a division of accident costs between manufacturers and users/victims.

APPENDIX E—SUITABILITY OF ANFO AS A FILLER FOR CRIMINAL BOMBS



Physics International
A Subsidiary of

2700 Merced Street San Leandro Ca 94577

10 January 1980
24 1393/0 084

Congress of the United States
Office of Technology Assessment
Washington D C 20510

Attention Mr Peter Sharfman

Reference: Your Letter of 11 January 1980

Dear Sir:

Referring to questions put to me by Mr David Garfinkle of Science Applications, Inc about the initiation and the damage potential of explosive devices loaded with ANFO, I would like to answer you with the following statements.

ANFO generally consists only of ammonium nitrate and fuel oil at a weight ratio of about 95 to 5 but may be used to designate other types of ammonium nitrate based explosives. The density is approximately 0.78 g/cm3, the energy density $E_0 = 2.9 \times 10^3$ J/cm3, and the ratio of specific heats of the gaseous products is $\Gamma = 2.554$. Under ideal conditions (i.e. quantities of several hundred kg and a strong initiation source) ANFO detonates at a rate of 5 km/s with a Chapman-Jouguet pressure (at the shock front) of 55 kbar. In small samples (e.g. 10 to 20 kg), even if confined, the detonation velocity is considerably lower, depending on confinement conditions and initiation, and typically between 1.9 and 2.8 km/s. The shock front pressure in these cases is also considerably lower than 55 kbar. Samples with small dimensions and negligible confinement will not detonate at all (e.g. cylindrical samples in thin plastic confinement 5 cm or less in diameter, or unconfined layers of 5 cm or less in thickness).

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Page 2

The ANFO commercially sold and used in the U.S.A. can generally not be initiated by a detonator only. A "booster" made of about 50 to 500 g of high explosives such as Composition C4, which can be initiated by a detonator only, is generally used to start the detonation. A criminal use of this type ANFO in quantities of 1 or 2 kg does not seem reasonable since the efficiency of a destructive explosive device under these circumstances would generally not be significantly improved beyond that resulting from the booster alone.

It is possible, however, to produce high explosives similar to ANFO which can be detonated by a detonator only. Some ANFO sold and used in the Federal Republic of Germany for mining and quarrying purposes has this property called "cap sensitivity". It is also possible to modify the composition of the blasting agent such that it becomes cap sensitive, e.g. by replacing the fuel oil by hydrazine hydrate. The sensitivity of ANFO can be increased by certain additives, e.g. aluminum powder or potassium perchlorate. In some cases, the sensitivity of the ANFO-like blasting agent can be increased by crushing the ammonium nitrate prills. Most of the premixed ANFO commercially sold in the U.S.A., however, does not become cap sensitive by crushing the prills. ANFO obtained by first crushing prilled ammonium nitrate commercially bought in the U.S.A. and then mixing it with fuel oil will also in general, not be cap sensitive. If either the ANFO or the ammonium nitrate used to mix it were obtained from certain areas outside the U.S.A., crushing of the prills may render it cap sensitive. In all these cases of "cap sensitivity" however, a high powered detonator (e.g. one containing 1 g base charge) is still needed, and also a certain amount of special information is required, whereas modern propellants as well as all types of black powder can be initiated by a heat source only like match heads, squibs, or even only an electrically heated wire or a spark.

The initiation requirements for various configurations are summarized in Table 1 below. It should be noted that this table is intended to give a general overview and that it cannot present all limitations, exemptions or special circumstances.

Table 1

MATERIAL	REQUIRED FOR INITIATION	
	CONFINED	UNCONFINED
Small amounts of commercial ANFO (-- 2 kg)	Booster charge of 50-500 g high explosive	(NO Reaction)
Large amounts of commercial ANFO (> 50 kg)	Booster charge of 50-500 g high explosive	Booster charge of 50-500 g high explosive
Sensitized ANFO or special mix blasting agent	Detonator with at least 1g base charge or 6" prima cord (50 grainift) + small detonator like below	Detonator with at least 1 g base charge or 6" prima cord (50 grain\ft.) + small detonator like below
Military explosive like Comp B or Comp C-4	Small detonator with about 25 g base charge	Small detonator with about 25 g base charge
Modern propellant or black powder	Heat source like matchhead, squib, hot wire or spark	(No explosion, only violent burning possible)

To compare the damage producing capability of destructive explosive devices, one has to consider air blast fragmentation, and potential incendiary effects. Assuming the initiation problems can be resolved for an explosive device containing only a few kg of a blasting agent similar to ANFO, then the air blast caused by this device could do approximately as much air blast damage as a device with the same weight of TNT (see Figure 1). The density difference between ANFO and TNT (approximately 0.8 vs 1.6) would require a larger confinement volume for a device containing ANFO.

Comparing fragmentation of a device loaded with TNT versus one loaded with a blasting agent similar to ANFO the latter would produce a smaller number of fragments larger in size and with a somewhat lower velocity than the TNT device. The total damage producing capability of the fragments of the ANFO device would probably come fairly close to that of the TNT device. Neither one of the two device types would produce any significant incendiary effect.

The damage producing capability of propellant or black powder loaded devices will generally be significantly smaller than that of devices loaded with an ANFO-like blasting agent due to the following reasons:

(a) The rate of energy release is much higher in high explosives, including blasting agents like ANFO, than in propellants including black powder. Expressed e.g. in Megawatts a 5 cm diameter device loaded with ANFO delivers energy at a rate of about 10,000 MW, a gun cartridge of the same diameter delivers energy at a rate of about 500 MW.

(b) The rate of detonation of high explosives including blasting agents like ANFO, is only weakly depending on ambient conditions whereas the propellant burn rate strongly depends on the ambient pressure. Propellants including black powder which are initiated in a metallic shell will frequently violently rupture the shell at a time when only a fraction of the propellant energy has been released, producing

> only very few medium velocity fragments and only a moderate pressure wave The burn rate of the still remaining mass of propellant will at the time of the shell rupture drop to a very low rate imposing no other danger than a fire hazard A high explosive or blasting agent detonated in a metallic confinement like a bomb shell will always produce a number of high velocity fragments and a strong air blast

To summarize, it can generally be expected that the damage producing capability of an explosive device loaded with an ANFO like blasting agent, if it is properly initiated, is somewhat smaller than that of a device of equal weight loaded with TNT, but significantly larger than that of a device of equal weight loaded with black powder or modern propellants.

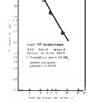
Very truly yours,

Roland R Franzen
Senior Staff Engineer

Attachment Figure 1

Figure 1.—Airblast Pressures From TNT and Field Mixed ANFO Fired on Ground

This figure was adapted from L. R. Sudler,
J. F. Pittman, Airblast Characteristics of ANFO,
U.S. Naval Ordnance Laboratory, White Oak, MD,
April 196



APPENDIX F—DERIVATION OF BOMBING STATISTICS TABLES

Chapters I, II, and V contain a number of tables summarizing the current and projected bombing threat. These tables were compiled from data originating from a number of sources including BATF, the FBI, FAA, and a number of other law enforcement agencies.

BATF and the FBI compile overall bombing statistics. The data, however, are available only in the form of periodic summary documents (semiannually from BATF and quarterly from the FBI) in compiled tabular form or in the form of individual case files. Both data banks are computerized, but the formatting does not make it possible to retrieve and analyze the data in a meaningful way. Management Sciences Associates had previously attempted an analysis of the BATF and FBI data bases as reported in reference F-1, and had been unsuccessful in retrieving the data in a manner which allowed meaningful analysis. OTA reviewed the BATF case file data, and concluded that analysis of the raw data files was not feasible, for the following reasons:

- the files did not contain all the data needed for the OTA analysis;
- files concerning cases currently before the courts could not be made available to OTA;
- the amount of effort necessary to analyze the individual data files was not commensurate with the time and funds available for the OTA analysis.

OTA conducted a similar (although less intensive) review of the FBI data files and concluded that detailed analysis of the FBI files would have the same limitations as listed above for the BATF files. In addition, fewer bombing incidents are contained in the FBI data.

The OTA analysis was therefore based primarily on the compiled summary reports. OTA had no reason to suppose that the data from any of these Government agencies were more or less reliable than the others, and so made use in each case of the data source whose formatting was most appropriate for the analysis in question.

In this appendix, the original tabular data from the FBI, BATF, and FAA are shown, and the way in which the tables in chapter VI were compiled from these sources is explained. The tables in chapters I and II were derived in turn from the chapter VI tables.

Table 54

The BATF data in table 54 are taken directly from tables 1 and 9 of the BATF 1978 Explosives Incidents Report (ref. F-2) reproduced below. The first five rows come from table 1, the last three from table 9. The FBI data comes from table 1 of the 1978 FBI Bomb Summary (ref. F-3) also reproduced below.

Table 9 of the *BATF 1978 Explosives Incidents Report* shows 435 injuries in 1978. This includes 250 fireworks accidents (listed as "unknown targets") and OTA therefore reduced the figure to 185 injuries from bombings.

Table 55

The explosive trend data in table 55 are also from the same FBI table 1. The only differences are that a column of total explosive bombings and attempts has been added and the property damage values have been rounded off to the nearest thousand dollars.

Similarly, figure 22 shows the same data in a graphical format.

Table 56

Table 56 on the determination of the explosive filler used in criminal bombs comes from two BATF sources. The 1978 "all identified fillers" data are based on table 13 of the 1978 BATF report (ref. F-2). A total of 1,797 cases is shown for 1978 in that table. This represents all of the explosive and incendiary bombings, criminal accidents, and exploded and undetonated actual bombs recovered during 1978 as shown by the first five rows of table 1 of the 1978 BATF report (ref. F-2). If those fillers which were not identified and the flammable liquids categories are removed, the number of cases involving identified explosive fillers from actual explosive bombings, recovered explosive bombs, and criminal accidents are 828. If the 1978 numbers for each type filler is divided by 824, then the percentages shown are found (rounded off to the nearest percent). The BATF category called "dynamite" includes dynamites, gels, slurries, and emulsions. The 1978 laboratory identified filler data are taken from page 83 of the BATF Annual Report for FY 78.

(ref. F-4). The "average" column is just arithmetic average of the other two columns. OTA believes these data give as accurate a feeling for the percentage of bombings for each filler type as can be derived short of a case-by-case examination.

Table 57

The data shown in table 57 are derived from two BATF sources. The total number of bombings against substantial targets was derived from table 8 of the 1978 BATF report (ref. F-2). The table shows [illegible] incidents, which corresponds to the number of actual explosive and incendiary bombings during 1978 plus the number of criminal accidents due to premature initiation, from table 1 of that report. From that was subtracted the number of bombings against unknown targets, mailboxes, and open areas from BATF table 9, to yield 1,286 bombings against substantial targets. The breakout between incendiary and explosive bombings was also obtained from data in BATF tables 1 and 9. Table 1 shows 866 explosive bombings (67 percent) and 440 incendiary bombings (33 percent). If the criminal accidents from the use of explosive and incendiary bombs are assumed to have occurred with the same relative frequency, then the total number of incendiary bombings and criminal accidents against substantial targets is equal to 33 percent of the 1,286 figure, or 423, while the number for explosive bombings is equal to 870.

The breakout of number of explosive bombings by type of filler was arrived at by using the percentage filler data from column 3 of table 56 and multiplying the percentage for each category by the 870 number of explosive bombings of substantial targets given above.

Neither the FBI nor the BATF data summaries break down deaths and injuries by the type of bomb filler used. However, A. Atley Peterson, Special Assistant (Research and Development) to the Director of BATF, gave a breakdown of deaths, injuries, and property damage by type of bomb filler before the 4th International Conference on Terrorist Devices and Methods in England during May 1979 (ref. F-5). These data are shown in table 57. Peterson's figure for total injuries, like OTA's table 54, excludes 250 injuries from fireworks accidents which are included in table 9 of reference F-2.

The row entitled "total for those fillers which would be directly tagged" aggregates figures for black powder, smokeless powder, and cap-sensitive dynamite, gels, slurries, and emulsions, corresponding to BATF pending documents and also to the OTA baseline case.

Table 58

Table 58 is BATF table 9 (ref. F-2) slightly modified. The words "property damage" were added to footnote a. Also, the number injured in 1978 from bombings of "unknown" targets was reduced to exclude 250 injuries from fireworks accidents.

Table 59

Table 59 is an OTA compilation based on BATF table 8 (ref. F-2). The percentage data are based on the average of the 1977 and 1978 bombings. The statistics for residences and vehicles and for commercial establishments come directly from that table. To get the percentage of identified substantial targets unlikely to be protected by a detection system, the unknown, other, mailbox, and open area bombings were removed from the data. That left 1,164 bombings of substantial targets (i.e., eliminating open area and mailbox bombings) in 1977 and 1,181 in 1978 in which the target was identified. It was then assumed that residences, vehicles, and commercial establishments would be unlikely to be protected by a detection sensor, while the other target categories might well be.

Table 60

Table 60 is an OTA-generated categorization of criminal bomber attributes.

Table 61

Table 61 was generated by the following process. First, a calculation was made of the proportion of bombings attributable to various types of bombers. This allocation was made by taking FBI data on apparent motives for the year 1974 (p. 4 of the FBI Bomb Summary 1974, ref. F-6), 1975 (p. 14 of the FBI *Bomb Summary* 1975, ref. F-7), 1976 (table 5 of the FBI *Bomb Summary* 1976, ref. F-8), 1977 (table 9 of the FBI Bomb *Summary* 1977, ref. F-9) and 1978 (table 4 of the FBI Bomb *Summary* 1978, ref. F-3) and averaging them. The FBI used different categories in each year and they were combined into the four OTA categories as shown in the tabulation below.

	1974	1975	1976	1977	1978
[illegible]					
[illegible]	✓	✓	✓		
[illegible]	✓	✓	✓		
Foreign [illegible]	✓	✓	✓		
[illegible]	✓	✓	✓		
Religious	✓	✓	✓		
Civil rights	✓	✓	✓		
[illegible]				✓	✓
[illegible]				✓	✓
Sabotage				✓	
[illegible]				✓	✓
[illegible]	✓	✓	✓		
[illegible]	✓	✓	✓		
Military [illegible]	✓	✓	✓		
[illegible]				✓	✓
[illegible]				✓	✓
[illegible]				✓	✓
[illegible]				✓	✓
[illegible]					
[illegible]	✓	✓	✓	✓	✓
[illegible]	✓				
[illegible]				✓	✓
[illegible]				✓	✓
[illegible]					
Malicious [illegible]	✓	✓	✓		
[illegible]				✓	✓
Vandalism				✓	✓

From the average for these 5 years, a calculation was made of the proportion of all bombings committed by each type of perpetrator: terrorists 12 percent, criminals 11 percent, mentally disturbed 38 percent, and vandals and experimenters 39 percent. The assumption was made that these proportions, calculated from bombings in which a motive had been attributed, apply also to those bombings where no motive is assigned by a law enforcement agency. The average number of actual explosive bombings for that 5-year period, taken from table 1 of the FBI *Bomb Summary, 1978*, was then multiplied by these proportions to yield the data in table 61.

OTA feels that the 5-year average is more appropriate than presenting year by year trends as the FBI categories have changed over that period with a substantial revision appearing between 1976 and 1977. In addition, the percentage of bombings to which the FBI assigns a motivation has changed drastically over that period. In 1974, 56 percent of the bombings were attributed while only 33 percent were attributed in 1978.

Table 62

Table 62 is taken directly from BATF tables 17 and 23 (ref. F-2), except that the BATF categories of TNT and dynamite were combined in the category "cap-sensitive high explosives" and RDX is included in the military explosives category.

Table 63

Table 63, on methods of entry for explosive theft, is simply BATF table 19 (ref. F-2). The first footnote has been slightly modified.

Tables 64 65 66 67

Tables 64, 65, 66, and 67 are taken directly from an FAA document FAA-RD-77-29 (ref. F-10). Table 64 is table 4 of the FAA report, table 65 is table 6 of that report, table 66 is table 7 of that report, and table 67 is table 14 of the FAA report. The only change in the tables occurs in table 66. Footnote a indicates that the identification of the explosive used in the LaGuardia bombing as dynamite and RDX is an FAA estimate; other agencies have offered different opinions.

Table 68

The premature detonation statistics in table 68 are from the 1974 through 1978 FBI bomb summaries, references F-5 (p. 3), F-7 (p. 6), F-8 (p. 12), F-9 (p. 6), and F-3 (p. 9).

Table 69

The commercial aircraft hijacking statistics in table 69 are from reference F-11, FAA report, FAA-RD-78-66, table 5, for the years 1949-76. The 1977 data are taken from the FAA semiannual report to Congress on the *Effectiveness of the Civil Aviation Security Program* for the period July through December 1978. The 1978 data were obtained directly from FAA officials.

Table 70

Table 70, concerning possible perpetrator countermeasures, was generated by OTA.

REFERENCES

F-1 — J. Roth, *Evaluation of the Needs and Benefits of the Explosive Tagging Program*, MSA report 317 [illegible], March 1979.

F-2 — BATF, *Explosives Incidents, 1978 Annual Report*.

F-3 — FBI, *Uniform Crime Reports: Bomb Summary, 1978*.

F-4 — A. A. [illegible], 4th Annual [illegible] Conference on *Terrorist Devices and Methods*, England, May 1979.

F-6—FBI Uniform Crime Reports Bomb Summary 1976.

F-7—FBI Uniform Crime Reports Bomb Summary 1978.

F-8—FBI Uniform Crime Reports Bomb Summary 1979.

F-9—FBI Uniform Crime Reports Bomb Summary 1977.

F-10—J. Bengston, P. Gatchis, and J. Henry, *Protection of Airports Against Explosives*, report No. FAA-RD-77-26, January 1977.

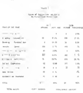
F-11—N. Ashe, P. Fox, C. Kennedy, and J. Kernan, *Analysis of Past Airline Hijacking and Bombing Incidents and the Present Defense Against Such Attacks*, report No. FAA-RD-78-56, December 1977.

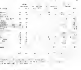
Table 54.—Minimum Bombing Incidents Statistics Summary

Item	BATF 1977	BATF 1979	FBI 1977	FBI 1979
Explosive bombings, number	1,107ᵃ	988	867	798
Unsuccessful explosive bombs, number	319	287	119	85
Incendiary bombings, number	339	440	268	349
Unignited incendiary bombs, number	83	7	55	79
Criminal accidents, number	2	67	—	
Property damage from bombings, millions of dollars	$11	$17	$9	$9
Injuries	90	65	102	55
People killed by bombings	38	23	22	18

ᵃBATF reported [illegible]

SOURCE: BATF [illegible] Explosives Incidents Report; FBI Uniform Crime Report Bomb Report, [illegible]





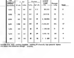


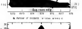
Table 55.—Explosive Bombing Incident Trends, 1972-78

Year	Total actual and attempted explosive bombings	Actual	Attempted	Total actual and attempted incendiary bombings	Actual	Attempted	Property damage (dollar value)	Personal injury	Death
1972	951	714	237	1,011	783	228	$7,992,000	1[illegible]5	25
1973	995	742	253	965	792	173	7,262,000	187	22
1974	1,129	893	236	915	758	157	9,887,000	207	24
1975	1,328	1,098	230	748	693	55	27,004,000a	326	69
1976	1,047	862	185	530	405	125	[illegible],085,000	212	50
1977	[illegible]	[illegible]	116	313	248	65	9,143,000	162	22
1978	873	768	105	423	348	75	[illegible]	135	18

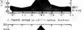
a Includes three major bombing incidents resulting in unusually high personal injuries and deaths and substantial damage to property.

SOURCE: FBI Uniform Crime Reports Bomb Summary, 1978.

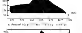
Figure 22.—Annual Bombing Statistics, 1972-77



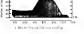
a. Number of incidents (includes attempts)



b. Property damage (excludes incendiary bombings)



c. Personal injury (excludes incendiary bombings)



d. Deaths (excludes incendiary bombings)

Table 56.—Identified Explosive Fillers Used in Bombs

	Lab Identified Bbms 1976	All Identified Bbms 1976	Average
Black powder	[illegible]	[illegible]	[illegible]
Smokeless powder	31	18	17.5
Military	2	7	4.5
Cap sensitive	32	30	31
Blasting agents	–		5
Chemicals	–		5
Others	36	21	28.5

SOURCE: [illegible]

TABLE [illegible]

[illegible]

TYPE OF INCIDENT	1975 NUMBER	1975 PERCENTAGE	1976 NUMBER	1976 PERCENTAGE
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

TABLE [illegible]

[illegible]

	NUMBER		PERCENTAGE	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

[illegible]

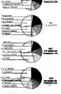


Table 57.—Bombing Casualties and Damage, 1976 by Type of Filler

Filler material	Number of bombings against substantial targets	Deaths	Injuries	Property damage $ millions
All fillers	[illegible]	23	165	$17.2
Incendiary	428	3	13	3.7
Black powder	48	4	19	2
Smokeless powder	52	3	23	2
Military explosive	38	0	7	
Cap sensitive	279	7	28	2.5
Other		3	40	2.4
Unknown		3	57	7.4
Total for those fillers which would be directly tagged	530	[illegible]	68	3.7

[illegible]

[illegible]

Source: [illegible]

Killed Injured and Property Damage by Explosives

CY1978

	BOMBINGS			[illegible]			TOTALS		
	K	I	PROPERTY DAMAGE	K	I	PROPERTY DAMAGE	K	I	PROPERTY DAMAGE
INCENDIARY		4	[illegible]	1	[illegible]	300,000		[illegible]	[illegible]
BLACK POWDER		1	74,759	—		—			74,759
SMOKELESS POWDER		23	[illegible]	1	1			2	[illegible]
MILITARY			[illegible]	1		200		24	[illegible]
DYNAMITE		28	[illegible]				8	38	[illegible]
OTHER		48	[illegible]	16	321	[illegible]		[illegible]	[illegible]
UNKNOWN		11	[illegible]	1	[illegible]	[illegible]		[illegible]	[illegible]
TOTALS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

Table 66.—Bombings by Specific Targets for 1977-78 (actual detonations or ignitions)

	Total incidents		No. killed		No. injured		Property damage[a]	
Type target	1977	1978	1977	1978	1977	1978	1977	1978
Residential	332	294	11	7	66	57	$ 1,022.3	$2,982.2
Commercial	367	375	7	6	48	46	4,640.8	8,777.7
Airports/aircraft	7		1			—		
Police facilities/vehicle	18	2					5	70
Educational	76	97	—	—	13	8	43	552.3
Government (local)	24	8	—			4	108.8	70
Government (Federal)	26	32	—	—	8	1	2.4	8.0
Military installations	4	5	—			1		0.0
Utilities	11	57	1			2	628.0	1,727.7
Banks	22	18	—		—	—	225.2	49.3
Vehicles	216	252	—	7	24	25	383.3	2,119.4
Open areas	36	40		2	8	3	5	4.2
Mailboxes	48	69	—	—		2	25.8	2
Other	90	137	—	—	8	27	1,206.8	869.9
Unknown[b]	34	2	—	—	8	2	22.6	0.0
Total	1,397	1,409	38	25	186	635	$10,331.7	$17,212.1

[a] Property damage figures are in thousands and are estimated.
[b] This category includes those incidents where the type target was unknown or not reported.

SOURCE: U.S. ATF, Explosives Incidents Report.

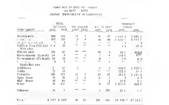


TABLE 9

BOMBINGS BY SPECIFIC TARGETS
FOR 1977 – 1978
(Actual Detonations or Ignitions)

TYPE TARGET	TOTAL INCIDENTS 1977	1978	NO. KILLED 1977	1978	NO. INJURED 1977	1978	PROPERTY DAMAGE[1] 1977	1978
Residential	352	294	17	7	66	57	1 022 3	2 982 2
Commercial	367	375	7	8	48	46	4 640	8 777 7
Airport aircraft	7	3	1	—		—	2	2
Police Facilities/Vehicles	14	25	—	—	—	—	5 8	70 4
Educational	106	97	—	—	12	5	45 1	552 3
Government (Local)	24	8	—	1	1	4	145 6	70
Government (Federal)	26	22	—	—	8		2 4	8 0
Military Installations	8	5	—	—	—	1	—	0 0
Utilities	5	57	2		1	2	528 8	1 727 7
Banks	22	18			—	—	225 2	49 3
Vehicles	216	252	11	7	24	25	383 3	2 119 4
Open Areas	36	40	1	2	8	3	5	4 2
Mail Boxes	48	69	—	—		2	25 8	2 1
Other	90	137	—	—	8	27	1 208 8	869 9
Unknown[2]	34	2	—	—	5	232	22 6	0 0
Total	1 397	1 409	38	25	180	635	10 331 7	17 212 1

1 Figures are in thousands and are estimated
2 This category includes those incidents where the type target was unknown or not reported

Table 5b Percent of Bomber Targets That Would Be Protected by a Detection System

	Total bombings		Injuries		Deaths	
Average number of bombings of known substantial target	1,176		150		29	
Bombings of residences, vehicles	557	(47%)	86	(57%)	21	(72%)
Bombings of commercial establishments	371	(32%)	47	(31%)		(22%)
Total likely to have sensors	928	(79%)	133	(89%)	28	(94%)

[illegible] 1976

[illegible]

SOURCE: BATF [illegible]

[illegible]

Table 80.—Attributes of Criminal Bomber Groups

Perpetrator	Experience and training	Resources	Motivation	Individual or group	Reaction capability	Frequency
Criminal						
Unsophisticated	L	L	M		M	Multi
Sophisticated	H	M	H		H	Multi
Terrorist						
Political	M-H	M-H	M-H	G	M-H	Multi
Separatist	M-H	M	H	G	H	Multi
Reactionary	L	L	H	G	L-M	Multi
Mentally disturbed						
Disenchanted	L	L	L-M		L	Single
Vengeful	L	L	M-H		L-M	Single
[illegible]	L-M	L	H		L-M	Varies
Other						
Vandals	L	L	L-M		L	Single
Experimenters	M	L	L-M		L-M	Single

L-Low; M-Moderate; H-High; I-Individual; G-Group

SOURCE: Office of Technology Assessment.

Table 81.—Estimated Number of Significant Bombings by Group of Perpetrators (average of years 1974-78)

Perpetrator group	Estimated number of bombings
Terrorists	72
Criminals	98
Mentally disturbed	340
Vandals and experimenters	348

SOURCE: Ibid.

BOMBING INCIDENTS BY TARGET AND APPARENT MOTIVE

Target	Total	Anti-Establishment	Anti-Religious	Civil Rights	[illegible]	For. Political	Labor Dispute	Malicious Destruction	Monetary Gain	Personal Animosity	Political	Racketeering	Suicide	Unknown	Other
TOTAL	2,044	141	8	28	20	4	24	[illegible]	27	80	11	13	2	80	1
Residence	960														
Private Residence	628	3					13	334	7	6	8	2		95	
Apartment House	5	3		4				11		86				2	
Other Private Property	79		1	4				32	1	6				0	
Commercial Operations	458														
Commercial Building	356	18		8	3		3	51	20	30	7	1		18	8
Office Building	38	3			0		5	7		1				2	
Industrial Building	30	2					10	4		1				4	
Theater	22				5	2	3	6		2			1	1	
Motel and Hotel	2	3						3		0		1			
Vehicles	237														
Auto	87	3	4				8	31	2	34		3		8	3
Other Vehicle	73	3		0			19	8		37		1		4	
Aircraft	2	3													
School Facilities	81	3					2	5		27					
Public Safety	79														
Law Enforcement	87	30						13		28		2			9
Fire Department	5									2					
Public Utilities	63	3					34	31	18	2	4				
Persons	44							6	2	29					
Recreation Facilities	28							30		2	2			1	
Transportation Facilities	37						8	25		2				2	
Government Property	29														
Federal	10	4						2		3					
State	8	1			3			2		3					
Local	18							11		3	4			1	
Construction Sites and Equipment	30						1		4	8	9			5	
Telephone Facilities	21					1			3	2				1	
Other Communication Facilities	3									0					
Military Facilities	19									8	3			8	
Churches	15	3	2					4		4					
Postal Facilities and Equipment	8							11		2					
Educational Establishments	16					4									
Guard Houses	1									4				1	
Medical Facilities	5							4							
Energy Facilities	8														
Open Area							1	96		3				8	5
Unknown (Premature Detonation)	29				2			2						5	6
Other	3				2			3	2	3					

BOMBING INCIDENTS BY TARGET AND APPARENT MOTIVE

	Total	[illegible]	[illegible]	[illegible] Rights	[illegible]	Other Political	Labor Dispute	Malicious Destruction	Monetary Gain	Personal Animosity	[illegible]	Racketeering	Unknown	Other
TOTAL	2,074	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Residences	502													
Private Residence	394	3			1		2	12	7	77			24	4
Apartment House	77							23		38			16	3
Other Private Property	32	4						[illegible]		17			7	
Commercial Operations	406													
Commercial Building	307	5		10	13	[illegible]	19	[illegible]	18	[illegible]	9	9	34	4
Office Building	39	3			5		2	4		[illegible]	1		[illegible]	
Industrial Building	27				3		13	3	2				3	
Theater	18						2	[illegible]		4				
Motel and [illegible]	4							[illegible]		3			2	
Vehicles	272													
Automobile	[illegible]				2		4	36	2	32		3	14	
Other Vehicle	[illegible]				2	3	8	9	3	12	2	1	5	
Aircraft	3												1	
School Facilities	65	4		38				25		6			8	
Law Enforcement	35													
Building	22	3			[illegible]			6		6			3	
Vehicle	33	3		3	3					[illegible]			3	
Other	2									[illegible]				
Government Property	62													
Federal	24				5	2		4					[illegible]	
State								[illegible]					3	
Local								[illegible]		3			4	
Persons	43							3		30		2	3	8
Public Utilities	41	[illegible]			[illegible]		2	[illegible]			1		0	
Recreation Facilities	35							24		3				
Telephone Facilities	29						2	[illegible]	7					
Other Communication Facilities	5									4				
Transportation Facilities	25			1			2	14	2				4	
Construction Sites and Equipment	20						[illegible]	[illegible]		2				
Postal Facilities and Equipment	17						<	[illegible]				4	3	
Churches	16		[illegible]	2				4		3			2	
Military Facilities	24							[illegible]		3				2
International Establishments	1					1								
Medical Facilities	10							3		[illegible]				
Courthouse	4	<		4	1	2								
Newspaper Facilities			1							[illegible]		[illegible]		
Open Area	36			2	2			[illegible]					8	3
Unknown (Premature Detonation)	37												13	9
Other	26							[illegible]					[illegible]	

Table 9
BOMBINGS INCIDENTS BY TARGET AND APPARENT MOTIVE
[illegible]

Target	Totals	Anti-Establishment	Anti-Religious	Civil Rights	[illegible]	Foreign Political	Labor Dispute	Malicious Destruction	Monetary Gain	Personal Animosity	Political	Racketeering	Subversive	Other
TOTALS	570	[illegible]	5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	16	[illegible]	[illegible]	[illegible]
Residences	433													
Private Residence	28	3		3	[illegible]		11	5	4	9				
Apartment House	40								[illegible]	[illegible]				
Other Private Property	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7
Commercial Operations	335													
Commercial Building	279	3		1	20	1	10	3	0	6	4	8		2
Office Building	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Industrial Building	23	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Theater	7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Motel and Hotel	5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Vehicles	32													
Automobile	142	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Other Vehicle	48	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Aircraft	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
School Facilities	124	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Law Enforcement	67													
Building	10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Vehicle	17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Other	20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Government Property	38													
Federal	13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
State		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Local	19	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Persons	42	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Public Utilities	28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Recreation Facilities	12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Telephone Facilities	23	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Other Communication Facilities	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Transportation Facilities	14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Construction Sites and Equipment	8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Postal Facilities and Equipment	26	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Churches	10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Military Facilities	4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] Establishments	11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Medical Facilities	4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Courthouses	4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Newspaper Facilities		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Open Areas	77	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Unknown (Premature Detonation)	42	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Other	20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table [illegible] BOMBING TARGETS AND APPARENT MOTIVES 1977

Target	Total	Animosity	Diversion	Extortion	Fraud	Intimidation	Labor	Protest	Publicity	Reprisal	Revenge	Sabotage	Subversion	Vandalism	Unknown	Other
TOTAL	[illegible]	113	7	6	4	43	12	28	57	23	26	8	4	[illegible]	493	23
Residences	27															
Private Residence	93	41		2		14			3	3	33					3
Apartment House	3	3				3										
Other Private Property	78	3				8	1							13	49	3
Commercial Operations	282															
Commercial Building	86	15		1	3	13		3	13	5	3	3		5	113	7
Office Building	28						1	3	8	1	1	3			1	3
Industrial Building	55			7		5		3	3	3		3				
Bank	29						3	3	3			<			1	
Theater	8			3		1			3						6	1
Motel and Hotel	6			2	1			4	3							
Vehicles	175															
Automobile	115	5				33	3		3	3	3					3
Other Vehicle	47	8				3		3	3		8					3
Aircraft	5					7										
School Facilities	88	3				3	27				3			37	4	
Law Enforcement	36															
Building	3						3				3				6	
Vehicle	5	1			4											
Other	18								3	1	8	<				
Government Property	66															
Federal	15						3		8					1	8	
State	11							3								4
Local	40	8					30	3							2	
Persons	58	9				3			3	5	3				38	3
Public Utilities	18					3		1	3				3		14	8
Recreation Facilities	7						3		1					2		
Telephone Facilities	5					3	3							2	9	
Other Communication Facilities	1							3								
In[illegible] Facilities	23					3			1	1				7	16	
Construction Sites and Equipment	32	1				3	4	3			8				12	
Postal Facilities and Equipment	15								1					1	5	
Churches	8														6	
Military Facilities	9						3	1	1						8	
International Establishments	3								1							
Medical Facilities												1				
Courthouses	3						1								5	
Newspaper Facilities	3														3	
Open Areas	78					3	23	1	3					1	48	6
Unknown Premature Detonation	29	1					7			1		4		2	11	7
Other	23					3	8	3	7		8	4			1	

Unless [illegible] motive [illegible] based [illegible]

Table 7. BOMBING TARGETS AND APPARENT MOTIVES 1974

Targets	Total	Animosity	[illegible]	Extortion	[illegible]	[illegible]	Marital	Profit	Publicity	Racial	Revenge	Subversion	Vandalism	Unknown*	Other
TOTAL	1,331	2..			3	4	Q	4.			8	--	2	--	S
Residences	341														
Private Residences	215	4				u	2			5	8		5	34	8
Apartment House	53	3				1				2	4			40	
Other Private Property	73	8					7				1			45	3
Commercial Operations	270														
Commercial Building	150	13			2	5	4	4	3		6		1	35	6
Office Building									3					8	
Industrial Building	11						1	3						6	3
Bank	10							2	.0					4	
Theater	10					0		1					1	5	
Motel or Hotel	1													5	
Vehicles	178														
Automobile	142	7			2	5	1			2	2		3	97	
Other Vehicle	36	6				1				2	8		1	23	
Aircraft														.0	4
School Facilities	10						2	3		1			8	43	
Public Safety	4														
Law Enforcement	38														
Building	1													6	4
Vehicle	23							1			1			9	
Other	4										1				
Fire Department and Equipment	3						1							1	
Government Property	5														
Federal	1						2	2						6	1
State														1	
Local	10						3							12	1
Persons	11	0						1		2	5	,		35	6
Public Utilities	5						1	1				2		9	6
Recreation Facilities	19						2				8	.4		15	
Telephone Facilities	41						3							19	1
Other Communication Facilities															
Transportation Facilities	31	2						2					1	24	5
Construction Sites and Equipment	10									1			*	1	
Postal Facilities and Equipment	4												2	2	
Churches	9													1	
Military Facilities	1											2	1	2	
International Establishments	7							3					1	3	
Medical Facilities	3													2	
Courthouse	8				5									3	
Newspaper Facilities	5							1						4	
Open Area	46	2					6		<					30	
Unknown Premature Detonation	33						9					*		16	8
Other	5										1		2	22	3

* Unless a feasible motive can be determined for each bombing incident, the motive is listed in the Unknown category

Table 1 BOMBING INCIDENTS 1972 through 1978

Year	Total Actual and Attempted Bombings	Actual		Attempted		Property Damage (Dollar Value)	Personal Injury	Dead
		Explo.	Incend.	Explo.	Incend.			
1972	1 962	714	720	237	219	$ 881,815	176	25
1973	1 955	742	787	253	173	7 261 832	187	22
1974	2 044	893	758	226	167	9 858 583	207	24
1975	2 074	1,098	813	238	135	27 003 981*	326*	69
1976	1 570	852	405	188	125	11 265 426	212	50
1977	1 318	867	248	116	85	8 943 300	162	22
1978	1 301	768	349	115	79	9 161 483	135	18

*Includes three major bombing incidents resulting in unusually high personal injuries and deaths and substantial damage to property

Table 62.—Stolen and Recovered Explosives Summary

Type	Amount stolen 1977	Amount stolen 1978	Amount recovered 1977	Amount recovered 1978
[illegible], pounds	[illegible]	[illegible]	[illegible]	[illegible]
Black powder, pounds	148	379	277	723
Smokeless powder, pounds	[illegible]	983	11	351
Boosters, pounds	2,177	8 528	2,814	382
Military explosives, pounds		140	648	701
Cap-sensitive high explosives, pounds	38 498	44,590	43 738	4[illegible] 087
Fuse, units	1,200	4,333	2 733	346
Blasting caps, units	61,551	58,654	49,719	44 468
Det. cord/safety fuse/igniter cord, feet	143 226	115 511	84,554	101 117
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

SOURCE: BATF, ATF Explosives [illegible] Report

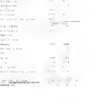


Table 83 Explosives Thefts by Method of Entry-
Number of Incidents and Percentages for 1977-78

	Number		Percentage	
Entry method	1977	1978	1977	1978
Lock cut	28	7	[illegible]	28.9
Lock pried	36	50	5.9	19.0
Door pried	[illegible]	9	5.3	3.5
Key	14	23	7.4	8.8
Window entry	7	3	3.7	1
Inside help	3	0	1.6	
Wall entry	10	16	5.3	6.
Burning	2		1.0	.4
Roof entry	7		3.7	1.1
Door blown	1	2	.5	.8
Floor entry	0			.4
Vent entry	1		.5	.1
Other	40	80	2[illegible]	30.4
Unknown	37	99		
Total	327	392	[illegible]	100

ᵃThese percentages do not include 37 cases where method unknown for 1977 and [illegible] for 1978.

ᵇThis figure [illegible] those incidents where the entry method [illegible] not included in the above categories.

SOURCE: BATF, Explosives Incidents Report.

Table 8[illegible]

Entry method	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	31			
[illegible]	36			
Door [illegible]				
Key				
Window entry				
Inside help				
Wall entry	1	6	1.1%	
Burning				
Roof entry	7		2.%	
[illegible]				
[illegible]	0			
[illegible]			.3%	
Other	[illegible]	[illegible]	.2%	
Unknown				
Total			[illegible]	[illegible]%

[illegible]

Table 64.—Explosions Aboard U.S. Aircraft

Date	Carrier	Aircraft	Aircraft location	Bomb location	Outcome	Device
11/1/55	UAL	DC-6B	11 minutes after TO	Baggage	Airplane disintegrated—44 killed	Dynamite
7/25/57	WA	CV-240	47 minutes after TO	Lavatory	Passenger thrown out of lavatory—hole in aircraft side, plane landed successfully	Dynamite
1/6/60	NA	DC-6B	34 minutes after TO	Underseat passenger compartment	34 killed, ship disintegrated	Dynamite, dry cells
5/22/62	CO	707	39,000 ft	Timed container in rear lavatory	Tail blown off—45 killed	Dynamite
11/12/67	AA	727	102 minutes after TO	Rear baggage compartment	3 bags destroyed, aircraft saved	Black powder (?)
11/10/68	CO	727	24,000 ft	Lavatory	Fire and explosion in lavatory; extinguished by crew, plane landed safely	—
8/29/69	TW	707	Ground after hijack (Damascus, Syria)	Explosives thrown in cockpit after evacuation	No casualties from explosion	Grenades & satchel explosive
9/7/70	PA	747	Ground after hijack (Cairo, Egypt)		Demolished after evacuation	—
9/12/70	TW	707	Ground after hijack (Dawson's Field, Jordan)		Demolished after evacuation	
12/28/71	—	Turbo Cmdr	In hangar	Seat in cabin	Aircraft destroyed, hangar damaged; no casualties	—
3/8/72	TW	707	Parked on ground	Cockpit	No casualties (plane empty)	C-4
5/21/73	—	Navion	Parked on ground	Engine manifold	Not known	—
12/17/73	PA	707	On ground, Rome	Attack while loading	Fire damage: 30 killed, many injured	White phosphorous grenades
8/26/74	TW	707	On ground, Rome	Aft baggage compartment	Fire confined to local area; no casualties	C-4
9/8/74	TW	707	Over Ionian Sea	Aft baggage compartment	High-order explosion: 88 killed; aircraft lost	—
2/3/75	PA	747	In air, Burma	Lavatory (suicidal passenger set fire)	Extinguished by crew; minimum damage	Petrol and butane
12/16/75	—	Alouette Helicopter	On ground	Near fuel tank	$10,000 damage to aircraft	Blasting caps
7/2/76	EA	Electra	Parked next to fence	External near right landing gear	Explosion and fire destroyed main landing	Dynamite (3-4 sticks)
7/6/76		Helicopter	On ground	External under tail	Extensive damage	Dynamite

SOURCE: FAA Civil Aviation Security Service.

Table 65.—Location of Explosions Aboard Aircraft, 1949-79

	Worldwide		U.S. aircraft	
Location of explosion	Number	Percent	Number	Percent
Stowed	13	21		21
Baggage	(8)		(4)	
Cargo or freight	(5)		—	—
Ground attack	5	8	4	21
External attachment	7	11	3	16
Passenger or crew compartment	33	52		42
Lavatory	(10)		(4)	
Passenger compartment	(19)		(2)	—
Cockpit	(4)		(2)	—
Unknown	5	8	0	0
Total	63	100	19	100

SOURCE: Data supplied by FAA Civil Aviation Security Service.

Table 66.—Explosions and Devices Found at U.S. Airports, 1972-75

Date	Airport	Location	Effects	Comment	Device
3/7/72	Kennedy	Cockpit of TWA B-707	No explosion	Discovered by dog	C-4
3/8/72	Seattle	Baggage compartment (UAL flight)	No explosion	Extortion attempt; timer stopped	Sticks dynamite in aerosol cans, blasting caps
10/72	Denver	Attache case carried by individual	No explosion	Individual stated intent to blow up plane	4 sticks of dynamite
3/24/72	San Carlos, Calif	Hanging from belly of helicopter	Hole in ground at remote location	Removed by police	3 sticks of dynamite, fuse, and detonators
12/1/72	Grand Rapids, Mich	Paper lined container in terminal	No explosion	Device not engaged after emitting smoke	—
12/31/72	Austin	Concession area	Moderate damage	—	Incendiary (gasoline)
3/21/73	Los Angeles	On runway during approach of Continental Airlines plane	None	Thrown by individual on field	Molotov cocktail
3/28/73	Milwaukee	Locker	1 injury-moderate damage	Extortion attempt	—
[illegible]/73	Los Angeles	Locker	Did not detonate	Extortion attempt; located by dogs	—
11/30/73	Nashville	Locker	Did not detonate	Extortion attempt	Smokeless powder, timer initiator
3/1/74	Kennedy	Locker	3 injured-moderate damage		
7/21/74	New Orleans	(unknown)	No explosion	Removed by bomb squad	3-in long bomb with powder and fuse
8/1/74	Kennedy	Cargo building	No explosion	Removed	Cardboard container with explosive powder, fireworks fuse
8/6/74	Los Angeles	Locker	3 killed, 36 injured	—	
8/[illegible]/74	Johnstown-Cambria, Pa	Hangar	Hangar and aircraft destroyed	—	Probable incendiary (in 55-gal drum)
8/29/74	O'Hare	Men's room	Commode damaged	—	Probably firecrackers
9/14/74	Boston	Airline baggage room	Substantial damage	Bomb was in an unclaimed suitcase destined for Tel Aviv	Incendiary (?)
3/18/75	San Francisco	Near ticket counter	Minor damage	—	Probably firecracker
3/22/75	Honolulu	Lost & found baggage area	Did not detonate	—	Crude pipe bomb
3/27/75	Kingsford, Mich	Storage area	No explosion	Removed	—
7/22/75	Tampa	Baggage cart	1 injured	—	Firecrackers
1/17/75	Miami	Locker	Lockers and ceiling destroyed	—	
8/21/75	Miami	Dominican Airlines office	No explosion	Discovered by janitor, disarmed by bomb squad	Time bomb
1/8/75	Buffalo	Baggage claim area (2 bags)	No explosion	Checked bags unclaimed after flight; alarm turned off (inadvertently)	Black powder and gasoline
11/27/75	Miami	Subcontractor aircraft, behind wall panel in lavatory	No explosion	Removed	—
12/29/75	La Guardia	Locker	11 killed, 74 injured; substantial damage		Dynamite and PETN

[illegible]

SOURCE: FAA Civil Aviation Security Service

Table 57.–Results of Civil Aviation Security Program Passenger Screening

	1972	1973	1974	1978
Passengers (in millions)	182	201	[illegible]	252
Passengers denied boarding	5,265	3,454	2,853	(a)
Referrals to law enforcement	(a)	(a)	(a)	12,277
Persons arrested	3,656	3,186	3,501	2,464
Aviation offenses detected				
Carrying weapons or explosives aboard aircraft	774	738	1,147	1,264
Giving false information	244	655	485	227
Weapons detected				
Firearms	[illegible]	2,162	2,450	4,783
Explosive devices	[illegible]	3,458	14,926(b)	[illegible]
Ammunition fireworks	(a)	(a)	(a)	7,647
Knives	18,018	25,211	21,458	40,358
Other	3,203	30,744	58,984	55,030

(a) Data not collected in this form.
(b) Big figure includes fireworks and ammunition.

SOURCE: [illegible] Semiannual Report to Congress on the Effectiveness of Passenger Screening Procedures, [illegible]

Table 58.–Premature Detonation Statistics

Year	Incidents	Injuries	Deaths
1974	29	31	
1975	37	93	2
1976	42	42	
1977	29	34	2
1978	33	43	1

SOURCE: IME Survey.

BOMBING INCIDENTS BY TARGET

Target	Total Actual Attempted Bombings	Actual Explo.	Actual Incend.	Attempted Explo.	Attempted Incend.	Property Damage (Dollar Value)	Personal Injury	Death
TOTAL	[illegible]	385	258	56	157	[illegible]	[illegible]	24
RESIDENCE								
Private Residence		[illegible]	232	25	53	821 544		
Apartment House	69	11	48		7	278 141	2	
Other Private Property	79	55	20	4		20 948	2	
Commercial Operations	451							
Commercial Building	256	143	43	43	27	821 528	8	
Office Building	32	15	13	4	8	681 178		
Industrial Building	80	17	7	4		811 621		
Theater	2	8		4		32 461	2	
Motel and Hotel	2	7				178 600		
Vehicles	257							
Auto	81	84	56	59	8	134 100	8	
Other Vehicle	73	88	22	7	2	234 858	4	
Aircraft	2					60 000		
School Facilities	183	99	60	28	1	841 948	44	
Public **Safety**	72							
Law Enforcement	69	78	18	8	8	314 310	4	
Fire Department	3	—			8	—		
Public Utilities	65	54		8		307 781	2	
Persons	44	2	3	17	3	38,950	24	6
Recreation Facilities	38	24	6	8		25,990		
Transportation Facilities	37	17	4	7	3	223,278	28	3
Government Property	36							
Federal	10	6	7	2		65,900		
State	8	8	8			48 150		
Local	8		8	4		13,320		
Construction Sites and Equipment	10	22	8	7		490,450		
Telephone Facilities	20	17	2			69 323		
Other Communication Facilities	3		7			9,000		
Military Facilities	9	6		6	4	49 842		
Churches	5	5	8			97,200		
Postal Facilities and Equipment	8	8		1	3	625		
International Establishments	10	6		2		173 750	2	
Court **Houses**	7	2	4	1		47 750		
Medical Facilities	5			1		100		
Newspaper Facilities				—		2 500		
Open Area	117	54	30	11	6	395		
Unknown (Premature Detonation)	29	28		—		8 325	5	
Other	21	15	8	1		216 300		

BOMBING INCIDENTS BY TARGET

Target	Total Actual and Attempted Bombings	Actual		Attempted		Property Damage (dollar value)	Personal Injury	Death
		Explosive	Incendiary	Explosive	Incendiary			
TOTAL	2074	[illegible]	[illegible]	178	138	27,003,591	270	44
Residences	502							
Private Residence	361	187	108	31	46	393,586	28	11
Apartment House	22	22	36	10	4	764,470	18	
Other Private Property	133	92	26	6		37,265		
Commercial Operations	498							
Commercial Building	387	234	108	2	25	4,485,305	53	20
Office Building	33	25	2			679,380	5	
Industrial Building	37	32		6	5	14,538,598	7	
Theater	1	9			1	62,500		
Motel and Hotel	18	8	6	2		30,180		
Vehicles	273							
Automobile	201	96	54	35	18	181,030	9	1
Other Vehicle	63	37	20	3	3	1,049,145	3	
Aircraft	1			2		5,000		
School Facilities	163	10	40	8	1	383,533	8	
Law Enforcement	74							
Building	22	1	2	1		505,225		
Vehicle	29	13	18	4	3	261,8[illegible]	4	
Other	23	8	8	4		2,600	5	
Government Property	85							
Federal	54	4	2	3		306,506		
State	11	7				72,209		
Local	22	16	3		1	64,296		
Persons	41	38	4	1	1	30,025	29	30
Public Utilities	42	35	1	5	1	2,572,375		
Recreation Facilities	33	21	4	4	4	35,364	2	
Telephone Facilities	18	26				13,335		
Other Communication Facilities	6	5	1			11,060		
Transportation Facilities	25	15	2	3		681,840	35	11
Construction Sites and Equipment	20	11	5	4		715,108		
Postal Facilities and Equipment	17	13			1	5,800		
Churches	18		1	2		3,330		
Military Facilities	16	5	5	4	1	138,205		
International Establishments	1	18	1			87,846	4	
Medical Facilities	20	4	1	1		34,300		
Court Houses	4	3		2		6,315		
Newspaper Facilities		1				310		
Open Area	100	55	22	25	4	580	4	
Unknown (Premature Detonation)	37	36	1			38,573	6	2
Other	26	21	3	2		24,770		

Target	Total Actual and Attempted Bombings	Actual		Attempt		Property Damage (in dollars)	Personal Injury	Deaths
		Explo	Incend	Explo	Incend			
TOTALS	[illegible]	5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	50
Residence	471							
Private Residence	338	82	133	[illegible]	34	3[illegible] 500	13	5
Apartment Housing	[illegible]	13	[illegible]		3	622,360	5	
Other Private Property	115	9[illegible]				50,000		
Commercial Operation	315							
Commercial Building	270	136	90		[illegible]	3,[illegible]	4	
Office Building	20	8	9			294,725		
Industrial Building	23	13	4	8		512,550	8	
Theater	7	3				13,300		
Motel and Hotel	4		2			310,500		
Vehicles	192							
Automobile	142	73	38	18	14	141,111	8	
Other Vehicle	48	23	12	8	5	120,508		
Aircraft		7				1,025,000	1	
School Facilities	126	75	31	14	4	361,483	7	
Law Enforcement	47							
Building	10	6				4,475		
Vehicle	17	5	8		1	34,380		
Other	20	3	9	4	4	35,443	1	
Government Property	26							
Federal	10	3		4	1	5,530		
State	1	4				263,860		
Local	16	1	5		1	205,445		
Persons	61	37	8	32	8	623,450	56	[illegible]
Public Utilities	28	22	3	1		127,853		
Recreation Facilities	21	15	8		—	6,508		—
Telephone Facilities	16	14				15,[illegible]		
Other Communication Facilities	[illegible]					350		
Transportation Facilities	14	8		3	2	75,300	3	
Construction Sites and Equipment	16	14	3	3		566,150		
Postal Facilities and Equipment	10	13	1	2		17,504		
Churches	12	[illegible]	1			46,250	1	
Military Facilities	1	5				5,300		
International Establishments	1	5		4	[illegible]	150,390	4	
Medical Facilities	[illegible]	[illegible]		4		615		
[illegible]	[illegible]	8				1,122,850	2	
Newspaper Facilities	1	2		8			1	
Open Area	77	48	16	8	5	1,362	1	
Unknown (Premature Detonation)	6	45		4		3,950	6	
Other	35	27			3	443,335	3	

Table 1 BOMBING INCIDENTS / ARRESTS 1997

Target	Total Actual and Attempted Bombings	Arrests		[illegible]		Property Damage Dollar Amount	Personal Injury	Death
		Explo.	Incend.	Explo.	Incend.			
TOTAL	1,[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3,[illegible]	[illegible]	22
Residential	292							
Private Residence	193	86	71	2	11	405,[illegible]	9	—
Apartment House	2	9	1	1	2	1,[illegible]	1	—
Other Private Property	78	99	1	5	2	16,150	8	—
Commercial Operations	292							
Commercial Building	19[illegible]	111	44	29	1	1,[illegible]	20	1
Office Building	28	15	4	9		240,[illegible]	1	1
Industrial Building	26	11	1	8	1	372,[illegible]		—
Bank	20	11	1	2	5	401,[illegible]		—
Theater		1		2	1	204,[illegible]		—
Motel and Hotel	6	1		1		65,[illegible]		—
Vehicles	57							
Automobile	18	87	11	1	1	2[illegible]1,581	1	—
Other Vehicles	11	15	16	1	1	11,[illegible]		—
Aircraft	5	2	1		2	800		—
School Facilities	100	1	11	22	3	546,368	5	—
Law Enforcement	14							
Building	3	1	1		4	8,348	2	—
Vehicle	1		1			12,[illegible]		—
Other	10	9	5		6	9,500	2	—
Government Property	68							
Federal	15	11		1	2	59,[illegible]		—
State	[illegible]	11		1		18,[illegible]		—
Local	40	12	4	8		79,140		—
Persons	[illegible]	49	1	23	9	270,996	62	14
Public Utilities	35	20		4	1	[illegible]		—
Recreation Facilities	17	[illegible]	1		1	14,[illegible]		—
Telephone Facilities	3	3				12,200		—
Other Communication Facilities			1			300		—
Transportation Facilities	23	11	2	1	1	342,300		—
Construction Sites and Equipment	3	27	1			356,475		1
Postal Facilities and Equipment	5	5		1		1,[illegible]	—	—
Churches	6	1				[illegible] 500	—	—
Military Facilities	9	1		1		400	—	—
Financial and Establishments	3	2	—			2[illegible],300	—	—
Medical Facilities		[illegible]	[illegible]				—	—
Courthouses	1	4				1[illegible]0,411		—
Newspaper Facilities		1	1			3,200		—
Open Area	91	53	12	2	2	1,[illegible]	7	—
Unknown (Premature Detonation)	29	30				7,[illegible]	34	1
Other [illegible]	39	81	1		1	1[illegible] 952	2	—

ble 3: BOMBS/INCIDENTS TARGETS, [illegible]

Target	Total Actual & Attempted Bombing	Actual		Attempt		Property Damage (Dollar Value)	Personal Injury	Death
		Explo	Incend	Explo	Incend			
TOTAL	[illegible]	[illegible]	141	[illegible]	74	3,111,[illegible]	[illegible]	[illegible]
Residential	[illegible]							
Private Residence	[illegible]	84	[illegible]	[illegible]	13	547 [illegible]	14	
Apartment House	11	11	[illegible]	1	7	57,330	9	
Other Private Property	[illegible]	84		1		36,[illegible]	4	
Commercial Operations	274							
Commercial Building	180	108	4	1	10	1,570,420	3	
Office Building	33	4	1	1		1,854,731	1	
Industrial Building	31	7		4	1	220 216		
Bank	38	18	2	1		114,902	0	—
Theater	20	7	1	1		34,000	3	
Motel or Hotel		2	1	7		73,200		
Vehicles	178							
Automobile	42	56	4	7	[illegible]	141,366	0	
Other Vehicle	36	17	—	1	1	63 [illegible]		
Aircraft								
School Facilities	101	76	11	1	1	877 812	1	
Public Safety	11							
Law Enforcement	38							
Building	11	5	5	1		33,330	1	1
Vehicle	21	11	4	1	1	24,[illegible]		
Other	4	3				2,890		
Fire Department and Equipment	3	3				5,610		
Government Property	31							
Federal		7	4	2		17 0[illegible]		
State	3	2				205		
Local	1	1	3		1	51,548		
Persons	54	29	4	19	1	121,295	31	9
Public Utilities	3	2	1	8		372,461	1	
Paw ... Facilities	9	14	3			89,785		1
Telephone Facilities	7	16	1	3		5 220		
Other Communication Facilities	2	8				76,000		
Transportation Routes	37	29	5	2		26 [illegible]	2	
Construction Sites and Equipment	6	7	3			1 285, 450		
Postal Facilities and Equipment	4	3				5,509		
Churches	5	6	3			7 480		
Military Facilities	7	3	3			26,930		
International Establishments	7	3		3		12, 050	3	
Medical Facilities	3	1	2			2 000		
Drugs	3	1		2				
Supply Points	5	4				13 960		
Open Area	40	3	4	6	3	11 132	3	
Unknown (Premature Detonation)	33	32				7 150	10	1
Other	7	20	2	7		12, 948	3	

Table [illegible].—Commercial Airliner Hijacking Statistics by Year

Year	Hijackings U.S. origin	Hijackings foreign origin
1949-67	8	45
1968	5	14
1969	36	43
1970	20	50
1971	24	21
1972	27	28
1973a		17
1974	3	17
1975	3	1
1976	4	15
1977	[illegible]	NA
1978	[illegible]	NA

a U.S. antihijacking measures became fully effective
b U.S. airlines, [illegible] of point of origin
NA not available

SOURCE: FAA [illegible], FAA-ED-77-66

Table 6.—Hijacking and Associated Bombing Costs for U.S. and Foreign Airlines by Flight Origination
(hijacker and bomber fatalities at $300,000 each)

Year	U.S. originations				Foreign originations			
	No.	Total costs, $millions	Enplanements, millions	Cost per enplanement (dollars)	No.	Total costs, $millions	Enplanements, millions	Cost per enplanement (dollars)
1949	6	$[illegible]	18.0	$0.000	3	$0.23	11.7	$0.023
1950	0	[illegible]	20.7	0.000	3	0.01	12.0	0.001
1951	0	0.00	25.6	0.000		[illegible]	17.0	0.000
1952	0	[illegible]	29.7	0.000		0.11	18.0	0.034
1953	0	0.00	29.7	0.000		[illegible]	20.1	0.000
1954	0	0.00	35.2	0.000		[illegible]	23.0	0.000
1955	0	0.00	35.0	0.000	0	[illegible]	26.0	0.000
1956	0	[illegible]	39.9	0.000	0	[illegible]	31.0	0.000
1957	0	[illegible]	53.3	[illegible]	0	0.00	37.0	0.000
1958	[illegible]	7.41	53.1	[illegible]	0	7.07	38.0	[illegible]
1959	0	0.00	56.3	[illegible]	6	0.33	42.0	[illegible]
1960	0	0.00	62.3	[illegible]	7	0.93	49.0	0.019
1961	8	0.18	63.0	0.003	8	1.47	53.0	0.028
1962	0	0.00	67.8	0.000	2	0.07	58.0	0.001
1963	0	0.00	77.4	0.000		0.00	64.0	0.000
1964	0	[illegible]	84.5	0.000	9	0.00	70.0	0.000
1965	0	0.00	92.9	0.000	0	0.00	77.0	0.000
1966	0	0.00	115.1	0.000	5	0.63	91.0	0.007
1967	0	[illegible]	142.5	0.000	4	0.01	101.0	[illegible]
1968	11	0.13	162.2	0.001	14	0.48	115.0	0.004
1969	36	0.54	171.9	0.003	48	8.55	134.0	0.046
1970	20	0.77	169.9	0.005	59	60.95	141.0	0.432
1971	26	1.01	173.7	0.006	29	6.43	139.0	0.046
1972	27	2.80	191.4	0.013	29	11.01	178.0	0.062
1973	1	0.00	202.2	0.000	7	52.08	207.0	0.250
1974	3	0.03	207.5	0.004	17	29.12	218.0	0.135
1975	6	1.35	205.[illegible]	[illegible]	11	0.81	226.0	0.004
1976	9	1.80	223.5	0.008	18	9.15	247.0	[illegible]
Total	145	$[illegible]	2,958.5	[illegible]	295	$193.85	2,456.0	[illegible]

SOURCE: [illegible]

Table 73.—Possible Perpetrator Response Countermeasures to Taggant Program

	Criminal		Terrorist			Mentally disturbed			Other	
Countermeasures	Unsophisticated	Sophisticated	Political	Separatist	Revolutionary	Disenchanted	Vengeful	Pathological	Vandals	Experimenters
Taggant retrieval	—a	M	M	H	L-M	—	—			L-M
Fabrication of explosives	L	H	H	M	M	L	L	L	L	L-M
Secondary devices	H	—	L	L	M	M	M	M	M-H	L-M
Use of blasting agents if untagged	L	H	H	M	M	L	L	L	L	M
Theft, commercial	M	H	M-H	M-H	L-M	L-M	L-M	L-M	—	M
Theft, military	L		L	L	L		—	L	—	—
Illegal sources	L	H	H	H	—		—	—	—	—
Use of explosives manufactured before implementation of tagging	L	H	M	L	—	—	—		—	—
Vapor traps	—	L-M	L-M	—	L		—	L		
Other tactics	—	L-M	H	H	H	—	L-M	M	—	

aLikelihood of attempt.
bLikelihood of successful evasion of the attempted countermeasure: L = low, M = medium, H = high.

SOURCE: Office of Technology Assessment.

The glossary defines, for easy reference, some of the terms used in this study in ways that may differ either from normal English usage or from the technical vocabulary of the explosives industry.

ANFO. A mixture of prilled (or granulated) ammonium nitrate and fuel oil, which is the most commonly used "blasting agent" (q.v.). About half the ANFO used commercially is mixed in a factory and half is mixed at the site where the explosion is to take place. Sometimes other similar blasting agents are called ANFO.

Black powder. See "gunpowder."

Blasting agent. An explosive material that is too insensitive to be detonated with a #8 detonator. Because blasting agents are generally cheaper to buy, safer to store, and (because of regulations) easier to ship than cap-sensitive explosives (q.v.), their annual commercial use far exceeds that of any other explosive material. The most common blasting agent is ANFO (q.v.), but many gels, slurries, and emulsions are also blasting agents.

Bomb. In this study, a "bomb" refers to a device designed to cause death, injury, and/or property damage by means of an explosion. In the usage of many law enforcement agencies, incendiary devices (designed to cause death, injury, or property damage by means of fire) are also considered bombs. The context makes it clear whenever this report refers to incendiary as well as explosive bombs.

Bombing. In this study, a "bombing" refers to an incident in which an explosive device actually detonates and causes death, injury, or damage.

Cap-sensitive. An explosive material is said to be cap-sensitive if it can be detonated by a #8 detonator. Dynamites are cap-sensitive; blasting agents are not cap-sensitive. Confined gunpowders (q.v.) are cap-sensitive. In normal commercial practice, a cap-sensitive booster is used to detonate a non-cap-sensitive explosive material.

Catastrophic bombing. A bombing which causes death, injury, and/or substantial property damage.

Compatibility. A foreign substance (such as a taggant) is said to be compatible with an explosive material if the presence of the foreign material does not have any deleterious effect on the performance or safety of the explosive material under any conditions whose occurrence can reasonably be foreseen.

Criminal. Used in two senses in this study. In OTA's characterization of different kinds of bombers, "criminals" are those who have an economic motivation for committing crimes. Elsewhere, a "criminal bombing" is any bombing in violation of the law.

Detection taggant. See taggant.

Device. A bomb. The distinction sometimes made between a device and a bomb is not meaningful in the context of this study.

Encapsulation. In the context of this study, the coating of a taggant at the time of its manufacture with an inert material.

Explosive. In this study, an explosive material that is cap-sensitive and more energetic than a gunpowder (q.v.). Typical explosives include dynamites, some gels, some slurries, and high explosives such as TNT.

Explosive material. A material that is manufactured for the purpose of being exploded, generally in a blasting or shooting application. Explosive materials include blasting agents, explosives, and gunpowders. (q.v.)

Explosives incident. In the data collection procedures of some law enforcement agencies, explosives incidents include stolen explosives, recovered explosives, accidents, hoaxes, and undetonated bombs, as well as bombings (q.v.).

Gunpowder. In this study, the term is used to refer to any of the propellants commonly used by those who engage in shooting for sport. These comprise black powder (which, strictly speaking, is what the term gunpowder means), smokeless powder, and Pyrodex® (a black powder substitute).

High explosive. An explosive material that is both cap-sensitive and highly energetic.

Identification taggant. See taggant.

Incendiary. See bomb.

Permissible explosive. An explosive with a low flame temperature, specifically approved by the Bureau of Mines for use in underground mining.

Powder fines. Grains of gunpowder or fragments of such grains that are smaller than the grains of which the gunpowder is primarily composed.

Pyrodex®. See gunpowder.

Reactivity. Two materials are said to be reactive if mixing them under a specified set of conditions causes a chemical reaction. If the reactivity of a foreign substance and an explosive material exceeds a specified standard, they may or may not be incompatible, but must be presumed to be incompatible in the absence of information about the nature and conditions of the chemical reaction.

Smokeless powder. See gunpowder.

Substantial target. A person or structure as the target of a bomb. This study uses the term because a number of bombings are directed against mailboxes, open fields, or other targets suggesting that the purpose of the bomber is to create an explosion without causing very much actual damage.

Taggant. A microscopic particle added to a commercial explosive in order to facilitate law enforcement. Identification taggants carry a code making it possible to trace the batch of explosives and the chain of legal distribution; they are intended to survive a bombing, be recovered from the debris, and assist in tracing the source of the explosives used. Detection taggants permit a suitable sensor to detect the presence of the taggants (and hence the explosives) through enclosed packages, etc. Taggants of various kinds have been used for identification and detection purposes not related to commercial explosives (and additional such uses have been proposed), but in this study all references to taggants or tagging refer to the application of this technology to commercial explosives.

U.S. [illegible]

Taggants in Explosives

April 1980

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